GROWTH AND DISTRIBUTION OF THE CRAYFISH *Orconectes nais* IN KANSAS FARM PONDS

by

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PREFACE

Crayfish are native to wide areas over the world and introductions have expanded their distribution further (Huner and Barr 1980). These animals are currently used in physiology experiments for neuromuscular preparations, and they are often used for invertebrate dissections in biology classes. Crayfish are commercially important mainly for their value as both human food and fish bait.

The crayfish that is probably best known and most commonly found in the literature is the red swamp crawfish, Procambarus clarkii. This crayfish is extensively cultured in the southern United States. In Louisiana during the 1970's, this crayfish was harvested to the extent of 11 million kg/year. This annual crop was worth $ 5 million at on farm prices (Huner and Barr 1980).

Some research is now oriented toward maximizing production of P. clarkii and other cultured crayfish species. Population density has been regulated by stocking rates and harvesting schedules (Mills and McCloud 1983; Huner and Avault 1976). Studies have been done on the water quality requirements ot crayfish (Avault, de la Bretonne, and Huner 1974; Melancon and Avault 1976). Supplemental feeding with rice and other forage has been used to increase production in culture ponds (Romaire, Forester, and Avault 1978; Mills and McCloud 1983; Chien and Avault 1980).

Momot (1977) studied the results of a fishery for the crayfish Orconectes virilis in two lakes in Michigan. He found that selectively trapping male crayfish caused the fishery to collapse.

Little is known about the life history or environmental requirements of the crayfish species found in Kansas. Crayfish are common in many farm ponds, especially when these ponds are too shallow to allow predatory fish to overwinter in them. Crayfish tend to make the ponds turbid with their foraging and are believed by some to weaken dams by their burrowing (Gabelhouse, Hager, and Klaassen 1982). For these reasons, farm pond owners generally don't want crayfish in their ponds. On the other hand, commericial fish growers often harvest crayfish as an incidental crop. Small-scale operators have been known to make more money off these crayfish than the fish they were producing (Klaassen 1984).

Before the potential of Kansas crayfish as an economic resource can be estimated, the basics of the life histories of these animals must be determined. The purpose of this study was to gather basic information including: the growth ot crayfish over their growing season here in Kansas, environmental requirements for good growth, estimation of crayfish density and population size in typical farm ponds, and crayfish distribution within these ponds. Experiments were performed to see if the natural growth and distribution of these crayfish could by manipulated.

The crayfish studied in this work was Orconectes nais. This species is widely distributed throughout the central U.S. and is commom in Kansas farm ponds, but only general information concerning its life history is known (Williams and Leonard 1952). Male crayfish have elongated anterior swimmerettes (gonopods) that are used in spermatophore transfer. In this genus, the males occur in two alternating forms. Form I, the breeding form, is found in ponds throughout the year except for the summer

months. The gonopods of this form are elongated, deeply forked and cornified. Examination of Form I gonopods is required for positive taxonomic identification.

The Form II, or non-breeding type of male crayfish, is present from late spring into early fall. The gonopods of this type are shorter, softer, and only shallowly forked.

The female spermatophore receptacle, called the annularis ventralis, is located centrally on the ventral surface of the thorax between the last pair of walking legs. This structure is also of taxonomic importance.

Crayfish of this species are believed to mate in the fall and possibly on into the winter. The eggs are probably laid in March and are attached to the female's swimmerettes. After the eggs hatch in May, the juvenile crayfish remain with the female until they have molted 2-3 times (Williams and Leonard 1952).

This thesis is presented in the form of 4 independent papers. This preface serves as an overall introduction to these studies.

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Paper 1: GROWTH OF THE CRAYFISH *Orconectes nais* IN KANSAS FARM PONDS

INTRODUCTION

In terms of economic impact, crayfish are one of the more important freshwater invertebrate animals found widely distributed over the world. They are used for both physiology studies and general dissections at all levels of biological education. Crayfish are of economic importance primarily tor their value as human food and for fish bait. For these and other reasons, studies concerning the growth and production of crayfish are both relevant and important.

The species *Procambarus clarkii* for example, is cultured extensively in the southern United States. This species is an obligate burrower adapted to a wet/dry cycle. In Louisiana, during the 1970′s, harvests of *P. clarkii* were worth $ 5 million annually at on farm prices (Huner and Barr 1980).

Researchers have attempted to improve crayfish production. Avault et al. (1974) believed most poor harvests of crayfish to be due to oxygen depletion and or overcrowding. Romaire et al. (1978), Huner and Romaire (1978), Flint and Goldman (1977), and Mills and McCloud(1983) in their experiments all found that crayfish kept at lower densities grew faster than those at higher densities. Romaire et al. (1978) , Mills and Mccloud (1983) and Morrissy (1979) all found that supplemental feeding increased the growth rate of crayfish.

Crayfish species found further north have not been as thoroughly studied with the execption of Orconectes virilis studied in Michigan and Ontario by Momot (1977, 1978), and Momot and Gowing (1983). There is little information of the life history or environmental requirements of many crayfish species. Here in Kansas some small-scale fish farm owners have been known to make more money harvesting crayfish as an incidental crop than selling the fish they were attempting to produce (Klaassen 1984).

The object of this study was the crayfish Orconectes nais. This crayfish has a wide distribution throughout the central United States, and is common in Kansas farm ponds. Some crayfish of this genus are believed to mate in the summer possibly into the fall (Williams and Leonard 1952). We believe that this species may mate in the later part of this schedule since the majority of Form I males from the ponds we sampled were collected late in the summer (Table 1). The eggs are probably laid in early spring. The hatching probably occured in May since when we began sampling in early June the young crayfish had already been released from the adult females.

The purpose of this study was to estimate the growth rate, population size, and biomass of crayfish found in Kansas farm ponds.

METHODS

Two farm ponds, typical of those found in the Flint Hills area of Kansas, were used in this study. Pond 1 (Figure 1) was of medium clarity (0.13-0.40m secchi disc transparency), with a maximum depth of 1.7m and an area of 0.305ha when full. During the drought of the summer of 1983, the pond level dropped, and maximum depth decreased to 1.4m.

Pond 2 (Figure 2) was an older pond that was largely filled in. It was a very eutrophic pond with algae blooms leading to measured secchi transparencies ot only 0.08m. This pond had a maximum depth of 1.4m, and an area of 0.717ha. Because of the drought the maximum depth of this pond decreased to 1.0m by the end of the summer. The only fish found in either of these ponds was the fathead minnow, Pimephales promelas. Cattle were often present in these ponds since they were used for livestock watering.

Sampling procedure consisted of 8 transect lines leading perpendicular from shore to the center of each pond. Of these eight lines, one originated from each corner of the roughly rectangular ponds, and one from the middle of each side. Both ponds were sampled at 0.25, 0.75, and 1.25m, (unless the pond was shallower at the time), along each transect line. Pond 2 was also sampled at 0.5m. Figures 1 and 2 illustrate the sampling transects described above.

This sampling procedure was designed to approximated the pond bottom as a series of concentric adjacent belts. In Pond 1, the collections at 0.25m were assumed to sample a belt from 0.0 to 0.5m, collections from 0.75m sampled 0.5-1.0m, and those from 1.25m sampled 1.0-1.5m and deeper. The belts approximated in Pond 2 were 0.0-0.38m, 0.38-0.63m, 0.63-0.88m, and 0.88-1.3m along with any deeper areas. Using the above sampling method with the contour maps described previously, we were able to approximate the crayfish population found in each pond by summing up the calculated estimates tound in each belt.

In this study, crayfish were collected with the two open-ended box traps described in Paper Three of this thesis. These traps sampled an area of 1.0 m^2 and consisted of 6.4mm (1/4 inch) mesh hardware cloth wired around a welded angle iron frame.

Table 1. Growth Data from Pond 1, 1983.

	YOY (Young of year)					Adults				
Date	Number collected	Avg CL	sd	FormI %	Males min CL	Number collected	Avg CL	sd	FormI %	Males min CL
Jun 15	254	8.6	2.47	0.0	---	54	32.2	4.21	0.0	---
Jun 30	674	10.9	4.16	0.0	---	25	36.8	4.14	5.9	29.0
Jul 14	766	13.0	3.71	0.0	---	36	37.5	4.28	18.2	39.4
Jul 27	965	14.9	2.86	0.0	---	44	39.3	2.94	20.7	38.4
Aug 11	874	17.5	3.05	0.0	---	30	39.0	3.60	26.3	39.1
Aug 24	1031	19.2	2.96	0.0	---	33	37.7	3.15	18.2	42.3
Sep 21	1177	20.6	3.17	7.3	20.7	29	39.6	3.16	53.8	39.4
Nov 2	598	20.8	2.55	24.6	19.3	7	38.6	2.43	100.	36.2

Table 2. Growth Data from Pond 2, 1983.

	YOY					Adults				
Date	Number Collected	Avg CL	sd	FormI %	Males min CL	Number Collected	Avg CL	sd	FormI %	Males min CL
Jun 16	10	11.8	0.85	0.0	---	51	43.2	4.80	23.8	40.7
Jul 1	103	14.3	3.99	0.0	---	23	4.27	4.27	35.3	43.3
Jul 15	228	18.9	4.60	0.0	---	31	42.4	3.72	22.2	41.1
Jul 28	246	19.3	4.22	0.0	---	19	42.9	3.53	23.1	38.2
Aug 12	208	22.2	4.28	0.0	---	6	43.8	3.18	0.0	---
Aug 31	148	25.9	3.70	0.0	---	0	---	---	---	---
Sep 28	87	28.2	3.80	89.2	24.7	1	43.5	---	---	---
Nov 16	35	30.0	3.44	93.8	23.2	2	39.1	0.14	100.	39.0

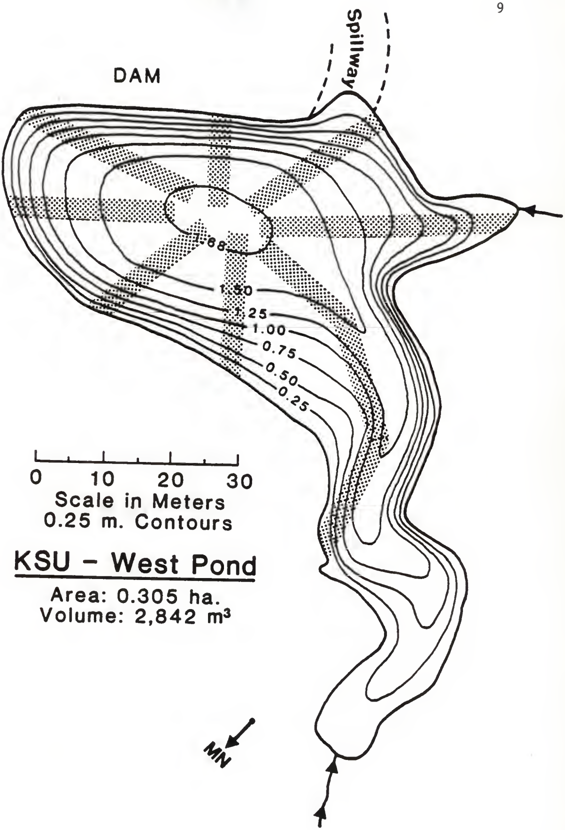

Figure 1. Contour map of Pond 1 showing sampling transects.

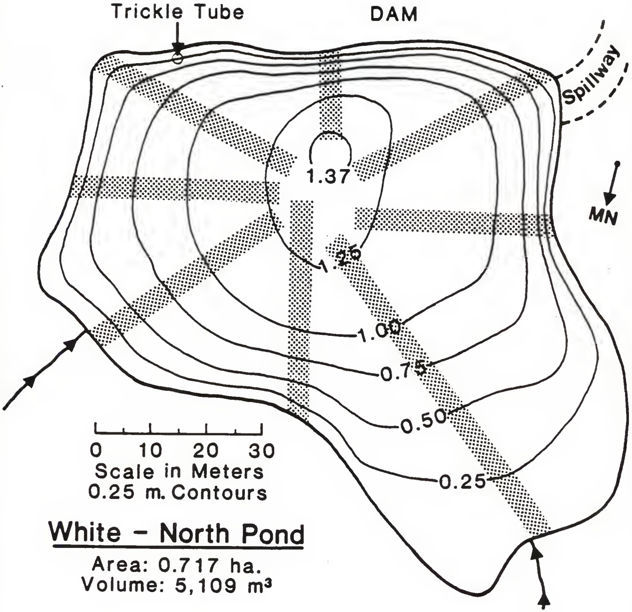

Figure 2. Contour map of Pond 2 showing sampling transects.

In order to simplify our sampling, we removed any habitat structure from the ponds that might serve to hinder our sampling devices. The structure removed was present mainly in shallower water and took the form of rock piles, tree limbs and brush.

When sampling the ponds, four 1.8m (6 foot) lengths of conduit pipe were used to hold the trap between us like a stretcher. We moved outward from shore along a transect line with the handles of the trap parallel to shore, keeping the trap well above water. At the proper depth we quickly lowered the trap and pushed its bottom edge into the mud. Once in place, the trap was scooped out with a long-handled dip net of 3.2mm (1/8inch) mesh. As described in Paper 3, this net was 71cm (28 inches) by 46cm (18 inches). Sweeps were made from one end of the trap to the opposite end, alternating from one side to the other side of the trap. After 6 sweeps, sweeping of the trap continued until 2 consecutive sweeps were empty.

Crayfish collected at each site were placed in buckets labeled for that site. After all the sites were sampled, adult crayfish were examined and measured. Their sex was noted as female or either Form I or Form II male. Distinct molting stages were also noted. The carapace length from the tip of the rostrum to the posterior dorsal edge of the carapace was measured to the nearest 0.1mm with a venier calipers. After these observations and measurements the adult crayfish were returned to the pond. The young of year (YOY) crayfish collected were preserved in 10% formalin. At the lab the carapace length of these crayfish was also measured, and if they were at least 6-8mm in carapace length they were sexed as well.

In 1982 the ponds were sampled at irregular intervals with a 1.2m x 6m (4 x 20 foot) 6.4mm (1/4inch) mesh bag seine. In 1983 the ponds were

sampled with the drop trap every two weeks from June-August, as well as once each in September and November. A total of eight crayfish collections were made during 1983.

RESULTS

Using the bag seine 3476 crayfish were collected and measured in 1982. The measurements of these crayfish were used with the 7393 collected with the box trap in 1983 in average length and weight comparisons.

Individual crayfish collected were carefully examined for taxonomic purposes. As described by Williams and Leonard (1952) they were identified as *Orconectes nais*. Sufficient numbers of crayfish were examined to recognize the presence of any different species in our collections. *O. nais* was the only species we ever found in these two ponds.

Length measurements collected over time were used to construct length frequency plots (Figures 3-6). These figures illustrate the percentage of the total number of crayfish collected at that date grouped into 2mm carapace length increments. In most of the length frequency plots at least two different age classes can be readily separated, YOY and adults. The distribution of the YOY age group is skewed to the right of a normal distribution in most but not all of the collections. The sexes were combined since there was no significant difference in their sizes during any sampling period.

When the plots from a single pond are lined up with the earlier dates at the top, the shifting of the distributions over time is an indication of the growth of crayfish in these populations. Since the scale of the ordinate was kept constant, the size proportions collected at each date

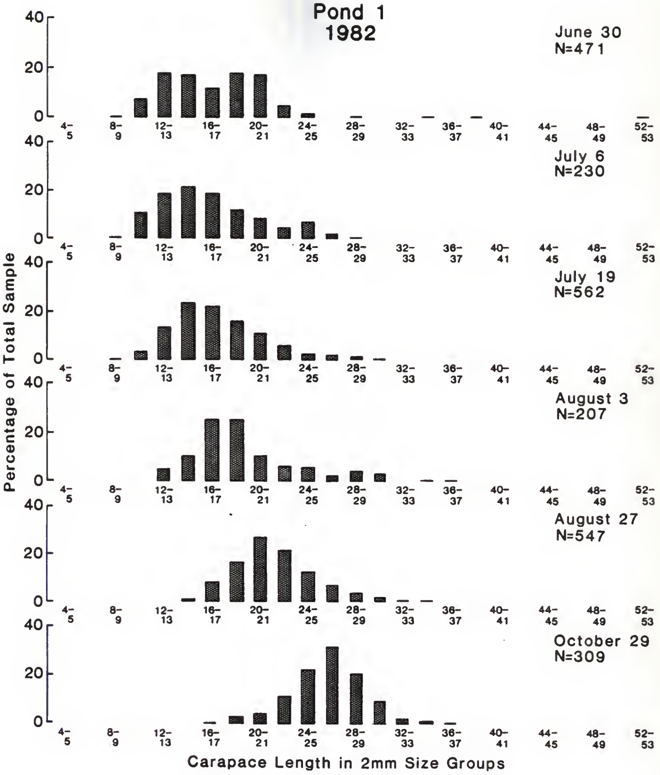

Figure 3. Length-Frequency plots of crayfish from Pond 1, 1982.

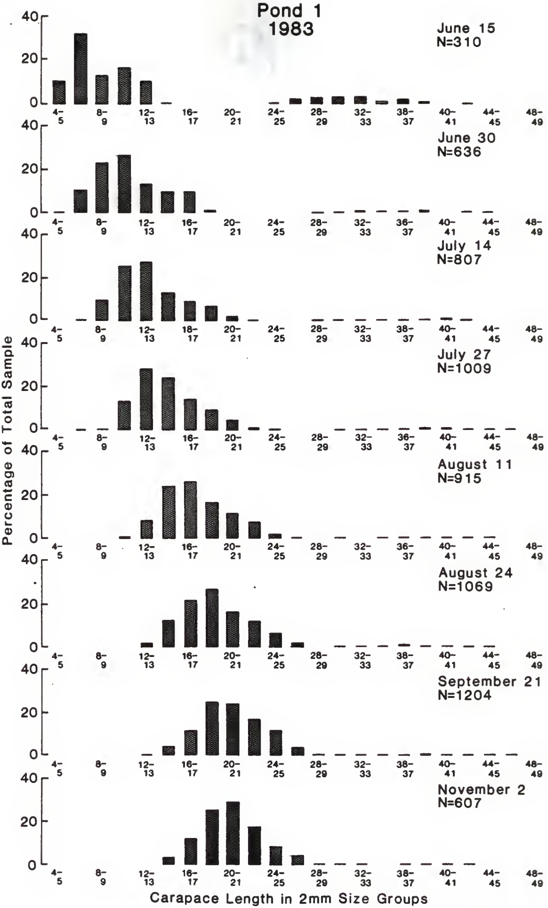

Figure 4. Length-Frequency plots of crayfish from Pond 1, 1983.

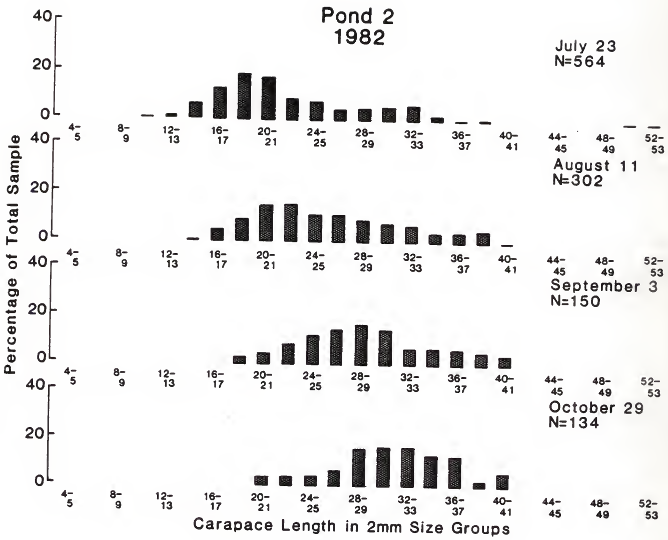

Figure 5. Length-Frequency plots of crayfish from Pond 2, 1982.

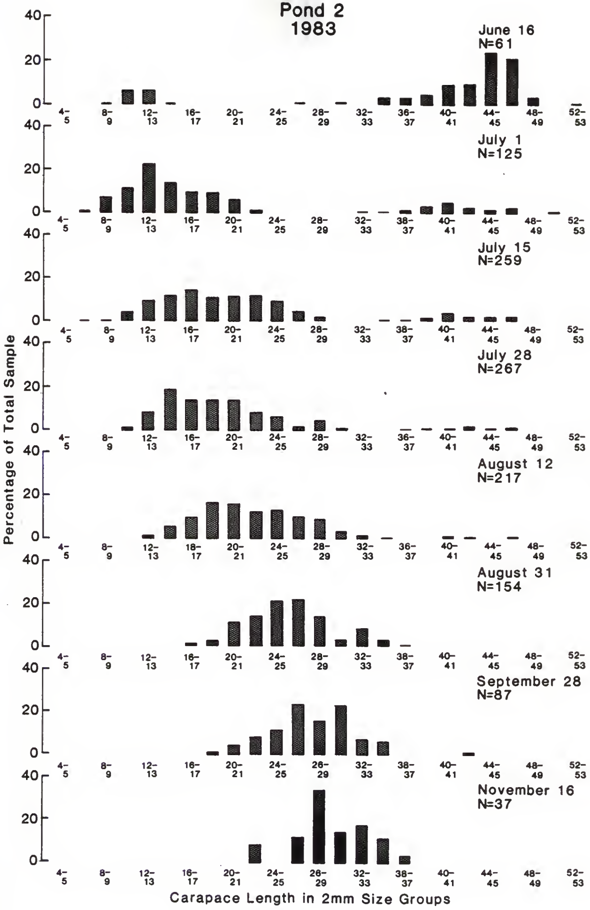

Figure 6. Length-frequency plots of crayfish from Pond 2, 1983.

can be compared directly. We considered these plots to be relevent indicators of the overall crayfish populations of these ponds and their fluctuations over time for two reasons. Sampling of these ponds did not commence until after YOY (young of year) recruitment for that year had been completed. With the low water levels present, especially in 1983, we saw no possibility for mass movement of crayfish either into or out from these ponds. These figures indicate that there is heavy mortality among the adult crayfish from early to mid-summer.

The modes of the size distributions of YOY at the end of the 1982 growing season correspond well with those from the first adult distributions from June 1983. In Pond 2 there is a definite overlap between the distributions from October 1982 and June 1983. Such an overlap indicated that little significant growth has occurred between these two collections.

The data from these collections are also shown in Tables 1 and 2. In these tables, the collections are categorized by age, sex and breeding condition.

Figure 7 is a plot of average length of YOY crayfish from both ponds over both seasons. Crayfish from Pond 2 grew to a larger size. In 1983, crayfish in Pond 2 grew to 30mm average carapace length (C.L.) vs. 21mm average C.L. for Pond 1 crayfish collected at about the same time. A total length of 75mm (about 38mm C.L.) is considered minimal for eating size crayfish (Huner and Barr 1980). (This size was not attained by crayfish from either pond in 1983). Figure 7 shows that crayfish from Pond 2 attained the same average size during both seasons. In Pond 1, The average crayfish was smaller at the end of 1983 than 1982. The smaller average of crayfish collected in 1983 compared to the previous year may be

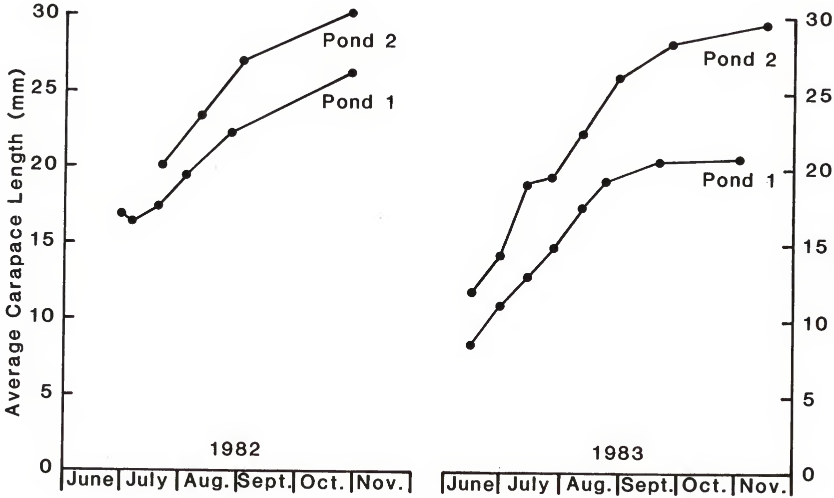

Figure 7. Average carapace length measurements of crayfish collected during 1982 and 1983.

due to a difference in density of this population between the two years.

Once a sufficient range of crayfish lengths were collected, (160 crayfish, 4-52mm in C.L.), length-weight relationships were constructed (Figure 8). When these data were put into the form of a log-log plot, wet weight in grams vs. carapace length in mm, the straight line relationship was calculated: Log_{10} Weight = -4.149 +3.372Log_{10} Carapace Length, r^2=0.994. This equation was used to determine the weights of all the crayfish collected. When the calculated weight of a crayfish collection was compared to its actual weight, the calculated figures were lower by 13%. This difference was probably due to the more thorough draining of the crayfish used to construct the regression equation.

Figure 9 shows the calculated average weights of YOY crayfish collected from both ponds over both years, wet weight in grams being plotted vs. time. This figure illustrates more clearly than Figure 7 the much larger size of crayfish from Pond 2. In Pond 2 crayfish reached a calculated average weight of 7.4 grams in both years vs. 4.6 grams in 1982 and 2.1 grams in 1983 for those from Pond 1.

The numbers and weights of crayfish estimated to be present in one of these ponds can be compared to the other one once the data has been converted to a per square meter basis. The contour maps (Figures 1 and 2) and a planimeter were used to approximate the area of the belts sampled. The number of crayfish estimated to be present within a belt was found by averaging the number collected in each of the 8 samples taken at that belt's contour. The total population of crayfish present within a pond was a weighted sum of the number present in each belt. Figures 10 and 11 plot the estimated total number of crayfish vs. time for Pond 1 and Pond 2 respectively for 1983.

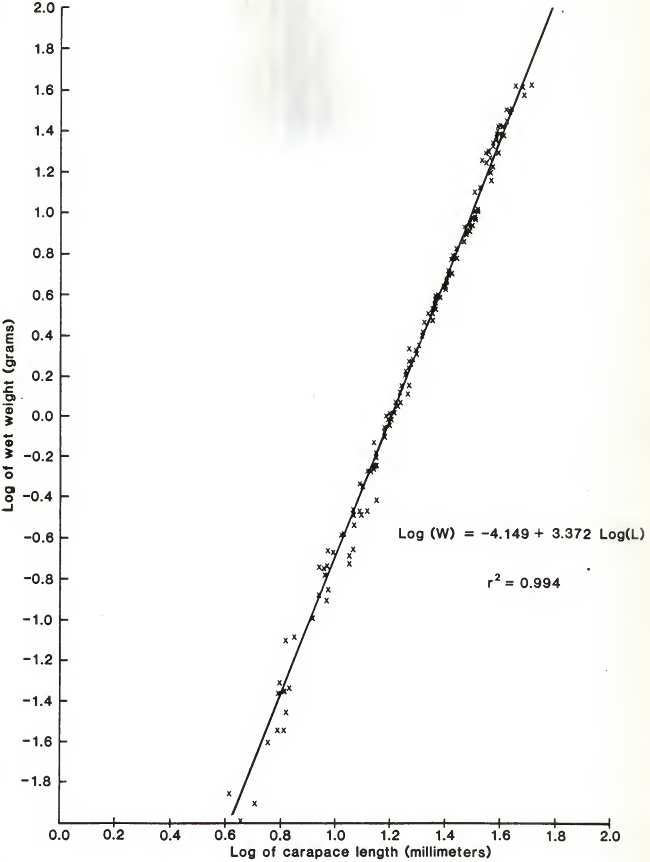

Figure 8. Log-log regression, carapace length vs. wet weight.

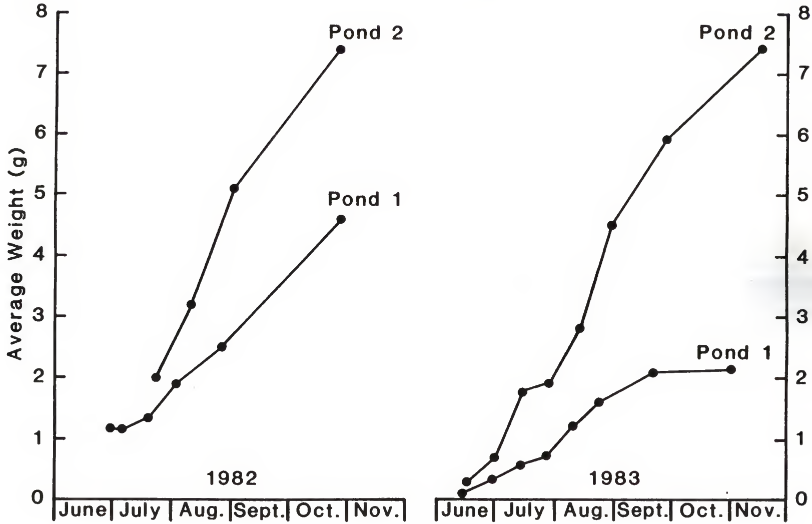

Figure 9. Average wet weight measurements of crayfish collected during 1982 and 1983.

Figures 10 and 11 show the total number of crayfish estimated in the ponds per hectare. In both ponds the numbers appear to build up to a peak. The increase before the peak probably does not reflect an increasing population, since very small crayfish were not collected over that time period. It more likely signifies the increased efficiency of the sampling method as the crayfish got larger. It is possible that the dip net skipped over the smaller sized crayfish caught in the trap or pushed them into the mud. Either of these occurrances would lead to larger crayfish being sampled more effectively. This would explain Pond 2 reaching a peak in its calculated population before Pond 1, they were being sampled more efficiently because they were growing faster. Since the summer was hot and dry, and the pond levels were dropping, we see no possibility for either of these ponds to increase their crayfish populations through recruitment or immigration over the months they were being sampled. We consider the population peaks to be appropriate population estimates and the decline from them a reasonable indication of the mortality rate. In Pond 1 the total crayfish population was estimated to peak at 470,000/ha compared to 75,000/ha for Pond 2.

Figures 10 and 11 show that few adult crayfish were present in the crayfish populations of either pond. Their numbers are represented by the gap between Total number estimated and YOY estimated. In Pond 2 in particular, few adult crayfish were collected after mid-August (Table 1).

Crayfish biomass estimate present in one pond was compared to the other once the data were transformed to a kg/ha basis. The estimated crayfish biomass present in Pond 1 reached a peak of 1180 kg/ha in September (Figure 12). Figure 13 shows a dramatic decline after the first day of sampling in Total crayfish biomass present in Pond 2. This decline

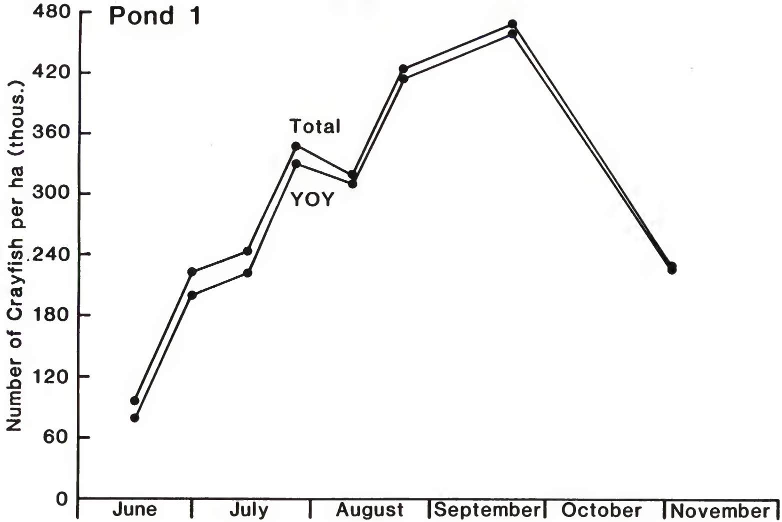

Figure 10. Estimated number of crayfish per hectare present in Pond 1, 1983.

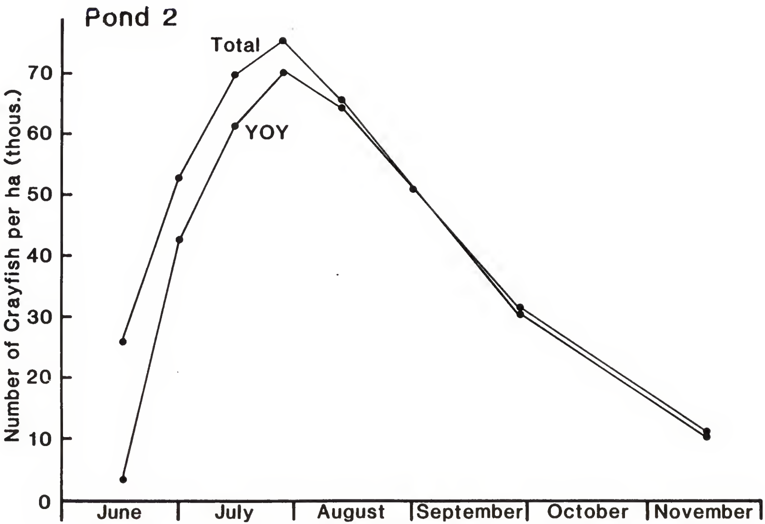

Figure 11. Estimated numbers of crayfish per hectare present in Pond 2, 1983.

represents a very heavy mortality of adult crayfish early in the summer months. As the YOY grew they reached their biomass peak at the end of August at 230 kg/ha. The decline there after was due to mortality.

DISCUSSION

Many researchers have analyzed the growth of various species of crayfish. Boyd and Page (1978) estimated that O. kentuckiensis YOY grew at a maximal rate of 4.3mm/month. Also using YOY crayfish, but growing them in large tanks, Morrissy (1979) observed a growth rate of 36g over a four month period. Momot (1965) concluded O. virilis on average measured 30mm carapace length after one year, 36.5mm after 2 years, and males surviving 3 years would reach 40.8mm in average carapace length. Tack's (1942) measurements of Cambarus (now Orconectes) immunis documented that this species grew to 23.7mm C.L. in its first growing season. Jackson's (1972) measurements of O. nais demonstrated that the crayfish he studied grew more slowly than those we measured. In his study in took crayfish 2 summers to reach 30mm C.L. while in Pond 2 of our study, many crayfish exceeded this length by the end of their first summer.

It would be difficult to conclude what factor(s) were responsible for the differences in growth rate of O. nais calculated in different ponds. Payne (1978) concluded that factors including availability of food, water quality, water temperature and predator pressures account for variations in growth rate and development of crayfish.

A study of the DO levels found in these ponds (Paper 2) has shown that the water quality of Pond 1 was superior to that of Pond 2. Pond 2 was very eutrophic, by mid-July its water was bright green, and its secchi disc transparencies were 4cm or less. On the basis of water quality

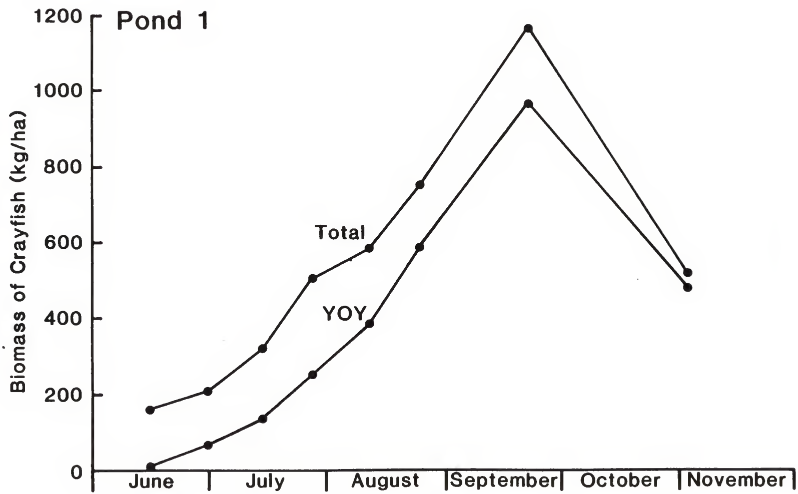

Figure 12. Estimated crayfish biomass present in Pond 1, 1983.

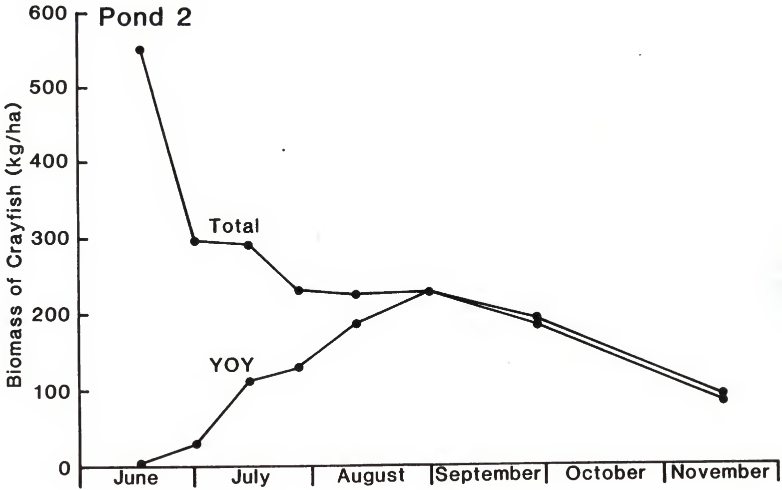

Figure 13. Estimated crayfish biomass present in Pond 2, 1983.

alone, one would expect crayfish in Pond 1 to grow faster than those in Pond 2, but as stated above, the opposite is true.

The very high crayfish density reached in Pond 1 (Figures 10 and 12) is probably the major factor for their slow growth. Much study on crayfish has centered on the densities their populations can reach. Avault et al.(1974) considered overcrowding to be a result of underharvest of crayfish culture ponds. The smaller size of individuals present in these dense populations otten leads the owners of them to stop harvest of the pond altogether. Huner (1978) also comments on the importance of density dependent factors in the management of crayfish stocks. Some values measured for crayfish density are recorded by Jackson (1972), 80,000/ha; Camougis and Hichar (1959),3,800/ha; and Abrahamsson (1966),20,000/ha. All of these being much lower than the 470,000/ha reached in Pond 1. This wide variation in density values could be due to several factors, including the fact that different species having various geographic distributions and habitats were included. The different results are most likely a product of the different methods used to reach the density estimates. For example, the structure provided on the pond bottom by the lift nets Jackson (1972) used may have been concentrating the crayfish of the pond at its location. Paper 3 of this thesis outlines some of the difficulties involved in making density approximations and how we believe our procedure may have surmounted some of them.

In this study there were many more crayfish per hectare in Pond 1 than in Pond 2. Figures 10 and 11 show that crayfish density in Pond 1 was generally 10 times greater than that estimated for Pond 2. It is not clear what is responsible for this difference in densities. To our knowledge, crayfish had not been harvested from either pond. Although

relatively more adult crayfish were harvested in 1982 than in 1983, even when combined, these studies removed at most 5 % of the crayfish from either population. As mentioned above, Pond 2 had much lower levels of DO than Pond 1 (Paper 2 of Thesis). The low DO levels found in Pond 2, (often less than 1mg/l), may have caused higher mortality in its crayfish population. Crayfish predators including a mink, <u>Mustella vison</u>, some bullfrogs, <u>Rana catesbeiana</u> and northern water snakes, <u>Nerodia sipedon</u>, were observed in and around Pond 2. The magnitude of their effects on the crayfish population of this pond is not known.

It has been shown that crayfish demonstrate density dependent behaviors. Bovbjerg (1959) notes increasing speed of dispersal with increasing densities. Bovbjerg and Stephen (1971) also observed an increase in agonistic encounters with increasing densities. It seems likely that the more agonistic behavior that occured in a crayfish population the slower its growth would be.

Some studies have examined the effect high densities of crayfish have on their food supply and the immediate environment of their pond. Lorman and Magnuson (1978) consider crayfish to be herbivores ,predators, detritivores, shredders as well as collectors and scrapers. Covich (1976) concludes that if sufficient cover is present, high densities of crayfish can result when a population of these generalized consumers concentrate on a single source of food. Besides causing a large impact on this preferred food, he believes that high crayfish densities can prevent immigration of species having more restricted diets. Flint and Goldman (1977) found the depending on its density the crayfish <u>Pacifastacus leniusculus</u> had totally different effects on macrophyte and periphyton growth. When their density exceeded 69g $/m^2$ these crayfish reduced the

amount of macrophyte growth, while at lower densities crayfish increased the growth of these plants. They found periphyton growth to be maximal at crayfish densities below 130g $/m^2$. At very high crayfish densities, (above 203g $/m^2$), periphyton growth declined. Rickett (1974) reported that O. nais can control macrophyte growth in ponds to the extent of eliminating these plants completely. Jackson (1972) noted similiar effects on vegetation in his crayfish ponds.

No macrophytic plant growth was observed in either of the ponds we studied. Another pond roughly the same size of Pond 1, and located nearby was often choked with weeds. This pond contained a population of green sunfish (Lepomis cyanellus). It is likely that these predatory fish cropped down the crayfish population to an extent that the crayfish were unable to control the macrophyte growth of the pond.

Whatever their cause, variable growth rates appear to have an effect on the reproductive patterns of O. nais. This study provided information that supports Momot's (1965) belief that O. nais reproduce their second spring. As seen in Table 1 the majority of YOY male crayfish from Pond 2 were Form 1 (reproductive form) by November, as were a large fraction of those from Pond 1. The smallest Form 1 male collected from Pond 1 was 19.3mm C.L.. By the November 2 sampling of Pond 1, 61.4% of YOY males were 20mm C.L. or larger. These measurements are not intended to prove that all YOY crayfish 20mm C.L. are mature but indicates that many of them could be.

Many authors have described the heavy mortality of crayfish of this genus. Momot (1965) found in his study of O. nais that the percentage of adults caught in his samples dropped from 25 to 4% from mid-June to the end of July. Momot (1977) considered the large decreases in the general

population of O. virilis to be due to lack of food. Survival rates for second and third year male crayfish in Illinois were 0.199 and 0.028 respectively (Boyd and Page 1978). Female crayfish survival was 0.365 in year one and 0.029 in year two.

Some studies have shown mortality in adult crayfish to be largely specific to one sex. Abrahamsson (1966) in September stocked 165 male and 165 female crayfish into a pond having no other crayfish. By March, he recaptured 150 male but only 44 female crayfish. On the other hand, Tack (1942) noted very heavy mortality of Form 1 males after breeding had been completed. He speculated that this may be a mechanism to save food for the YOY recruited.

As seen in Table 1 and Figures 10 and 11 in our study adult crayfish present in both of the ponds we studied experienced heavy mortality over the period we sampled. In Pond 2, we seldom collected adult crayfish past mid-August. Adult mortality appeared equally large in both sexes.

We knew at the start of this study that crayfish are common in farm ponds of this state. We discovered that they can occur at very high densities in these ponds and reach biomasses exceeding 1100kg/ha. Because of the high overwinter mortality of YOY crayfish if they are to become a viable resource they must be grown to edible size within one growing season. The growth of crayfish in Pond 2 approaches that requirement. It appears to us that it was the high density of crayfish present in Pond 1 that slowed their growth, possibly food being the limiting factor. As described in Paper 4, supplemental feeding significantly increased the growth of caged crayfish. We conclude therefore that the necessary growth rates may be obtained provided that crayfish density be controlled and DO levels maintained.

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Paper 2: DISTRIBUTION OF THE CRAYFISH *Orconectes nais* IN KANSAS FARM PONDS

Introduction

Crayfish are found world-wide and are of economic importance for several reasons. They are used as dissection specimens at all levels of biological education. Physiological researchers have used them in neuro-muscular preparations. Crayfish are of economic importance primarily for their value as human food and for fish bait.

The crayfish studied in this work was *Orconectes nais*. Williams and Leonard (1952) consider this species to have a wide distribution throughout the central United States. Its distribution includes Kansas where it is commonly found in farm ponds. As noted in Paper 1, our work has indicated the eggs of this species hatch in May, and young crayfish are independent by early June.

The purpose ot this study was to examine the spatial distribution of *O. nais* found in Kansas farm ponds. This crayfish distribution was then correlated with measured environmental parameters.

METHODS

The two farm ponds used in this study are illustrated in Figures 1 and 2. Pond 1 had an area of 0.305ha and was 1.7m deep when full. Pond 2 was an older, very eutrophic pond that was largely filled in. This pond had an area of 0.717ha and was 1.4m deep when full. During the hot and dry summer of 1983, the water level of these ponds dropped making them 1.4 and

1.0m deep respectively. The only fish found in either of these ponds were fathead minnows, Pimephales promelas. We often found cattle in these ponds since they were used for livestock watering.

Any structure in these ponds that might have served as habitat, concentrating the crayfish was removed. These structures were present mainly in shallower water and took the form of rock piles, tree limbs, and brush. Removing these items from the pond bottoms simplified our attempts to correlate distribution of the crayfish with environmental parameters.

The sampling procedure of this study used 2 open-ended, drop traps is described in Paper 3 of this thesis. The two box traps used each had a sampling area of $1m^2$, one being 1.4m (4 foot 5 inches) tall, the other 1.1m (3 foot 5 inches) tall. These traps were carried into position held between us by 1.8m (6ft) conduit lengths. We moved outward from shore along a transect line carrying the trap until we reached the desired depth. The trap was then quickly lowered, pushed into the mud, and the trapped crayfish scooped out with a long-handled dip net. This net was 71cm (28 inches) wide by 46cm (18 inches) high of 3.2mm(1/8 inch) mesh.

Eight transect lines leading out from shore toward the center of the pond were spaced around the perimeter of the ponds. These lines were sampled at 0.5m, 0.75m, and 1.25m in Pond 1 and at 0.25, 0.50, 0.75, and 1.0m in Pond 2. This sampling procedure, illustrated in Figures 1 and 2, was designed to approximate the pond bottom as a series of concentric belts.

Crayfish collected at each site were placed in buckets labeled for that site. After all the sites were sampled, adult crayfish collected at each site were counted, measured, and then returned to the pond. After being counted, the YOY crayfish collected were preserved in 10% formalin

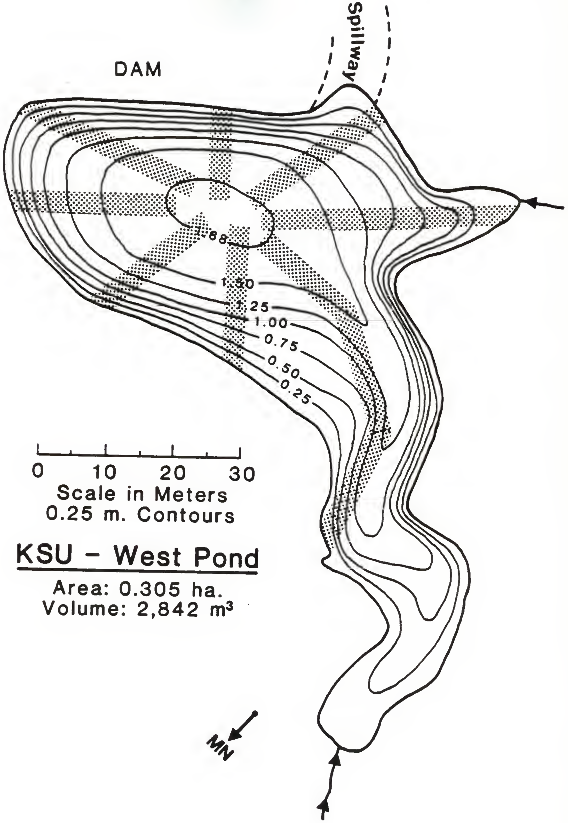

Figure 1. Contour map of Pond 1 showing sampling transects.

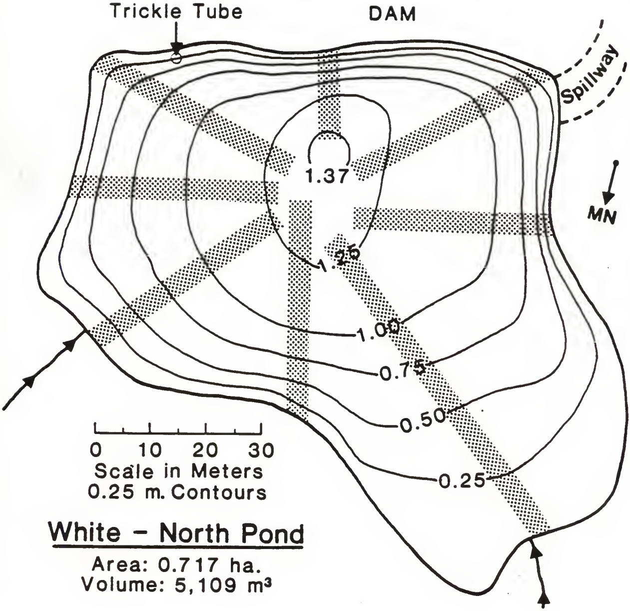

Figure 2. Contour map of Pond 2 showing sampling transects.

and returned to the lab where they were measured. The carapace length measurements of the crayfish were used in measuring the growth of these crayfish (Paper 1).

After crayfish sampling was completed, environmental parameters of the pond were measured. Dissolved oxygen (DO) and temperature profiles were measured from a boat using probes and meters. Secchi disc transparencies and water level were also noted (Table 1). DO and temperature measurements were also taken from bottom water samples collected within 2cm of the bottom. These samples were taken at depths the crayfish were collected at, along every other (4) of the eight transect lines.

The ponds were sampled at 2 week intervals from June-August, as well as once in September and November. A total of eight crayfish collections were made during 1983.

RESULTS

Using the above procedure, 7393 crayfish were trapped and measured in 1983. Individual crayfish collected were carefully examined for taxonomic purposes. Using taxonomic keys by Williams and Leonard (1952) they were identified as *Orconectes nais*. Sufficient numbers of crayfish were examined to recognize the presence of any different species in our collections. *O. nais* was the only species we ever found in these two ponds. During the hot dry summer of 1983, water levels of the ponds dropped and there were no mass movements of crayfish into or out from the ponds.

Figures 3 and 4 are plots of average bottom water dissolved oxygen concentrations of collections from Pond 1 and Pond 2 respectively. The data used to derive these plots are summarized in Tables 2 and 3. The

Table 1. Water level and clarity measurements from Ponds 1 and 2 during 1983.

Pond 1			Pond 2		
Date	Water Level(m)	Secchi Disc (m)	Date	Water level(m)	Secchi Disc (m)
Jun 15	+0.08	0.13	Jun 16	+0.01	0.08
Jun 30	+0.01	0.40	Jul 1	0.00	0.20
Jul 14	-0.11	0.30	Jul 15	-0.03	0.20
Jul 27	-0.29	0.29	Jul 28	-0.09	0.17
Aug 11	-0.41	0.28	Aug 12	-0.17	0.15
Aug 24	-0.48	0.28	Aug 31	-0.23	0.10
Sep 21	-0.64	0.15	Sep 28	-0.35	0.12
Nov 2	-0.64	0.20	Nov 16	-0.23	0.15

average bottom water DO measurements show little oxygen present at 1.0-1.25m until a late summer turnover occurred between the end of August and mid-September. Over this sampling season DO measurements fluctuated more at the deeper depths than at the shallower ones. Figures 5 and 6 show temperature profiles constructed from these same collections. The data used to construct these figures is summarized in Tables 2 and 3. These measurements were always taken in mid-afternoon. Both DO and water temperature would be expected to be lower earlier in the day. Figures 5 and 6 show the narrow range of temperatures throughout the water column. These data indicate these ponds were only weakly stratified. Bottom water temperature measured in these ponds remained mostly constant from mid-July through August. The sharp decrease in temperature evident in figures 5 and 6 also indicate that the ponds underwent a late summer turnover between the end of August and mid-September.

Figures 7 and 8 and Tables 4 and 5 show the average number of crayfish (YOY and adults) collected per square meter at each of the depths sampled in Pond 1 and Pond 2 respectively. In these two figures YOY comprised the great majority of the total number of crayfish represented. In neither pond were many crayfish found at the deepest contour until the late summer turnover. Collections during July and August often caught no crayfish at all at these deepest levels. Figure 7 shows that in Pond 1 when no crayfish were found at 1.25m, the average number collected at 0.75m peaked. When the average density at 0.75m peaked for the 1983 season on August 24, a single square meter collection at this depth contained 132 crayfish, 128 YOY and 4 adults.

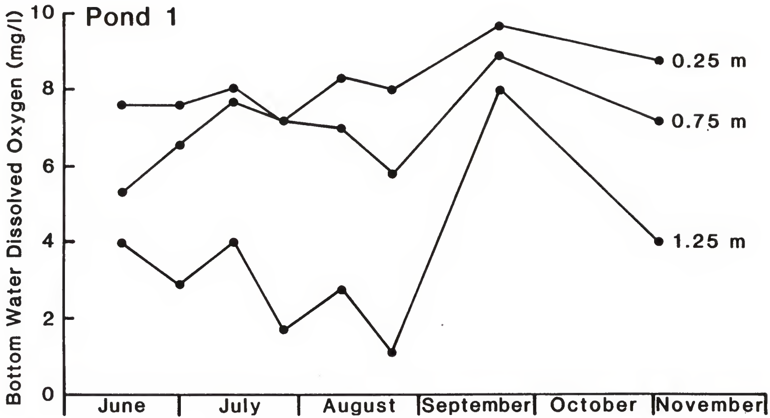

Figure 3. Dissolved Oxygen levels measured from bottom water samples collected from Pond 1,1983.

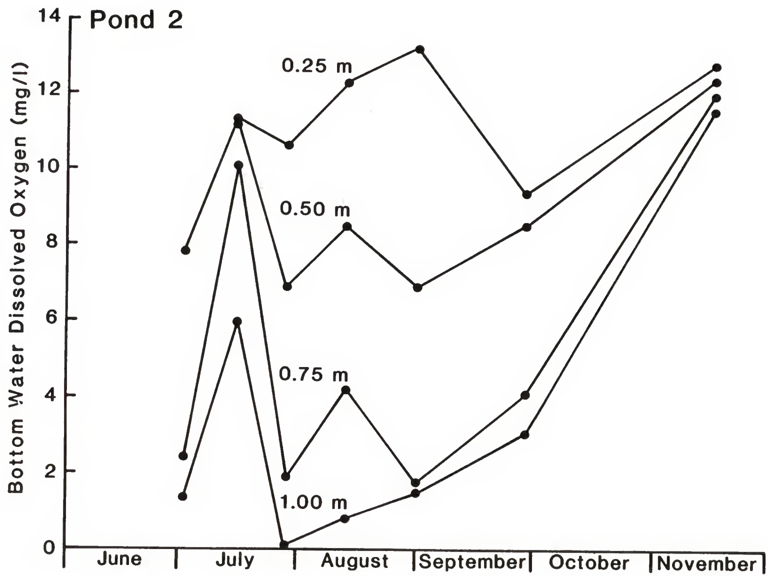

Figure 4. Dissolved oxygen levels measured from bottom water samples collected from Pond 2, 1983.

Table 2. DO and temperatures from bottom water samples from Pond 1, 1983.

		Dissolved Oxygen (mg/l)			Temperature (^{o}C)		
Date	Depth (m)	Mean	Range	sd	Mean	Range	sd
Jun 15	0.25	7.6	-----	---	27.0	-------	---
	0.75	5.9	-----	---	17.5	-------	---
	1.25	4.0	-----	---	16.3	-------	---
Jun 30	0.25	4.5	2.7-6.4	1.69	29.3	-------	---
	0.75	5.5	4.6-6.5	1.06	28.0	-------	---
	1.25	3.9	3.6-4.6	0.46	23.0	-------	---
Jul 14	0.25	7.9	7.7-8.1	0.16	30.0	29.0-30.0	0.57
	0.75	7.8	7.3-8.0	0.16	29.4	28.5-30.0	0.86
	1.25	3.5	1.9-5.0	1.04	27.8	27.0-28.0	0.57
Jul 27	0.25	7.2	7.1-7.4	0.11	30.8	30.3-31.2	0.48
	0.75	7.2	6.7-7.5	0.33	30.5	30.0-31.0	0.47
	1.25	1.7	0.7-2.8	0.83	28.0	27.8-28.3	0.29
Aug 11	0.25	8.3	8.1-8.7	0.33	30.9	30.5-31.2	0.37
	0.75	7.0	5.7-7.7	0.91	29.9	29.4-30.0	0.34
	1.25	2.8	2.4-3.1	0.30	28.9	28.7-29.1	0.21
Aug 24	0.25	8.0	7.6-8.5	0.37	32.1	31.4-33.0	0.77
	0.75	5.8	5.0-6.3	0.55	30.2	30.0-30.3	0.17
	1.25	0.9	0.1-1.9	0.77	28.2	28.0-28.9	0.51
Sep 21	0.25	9.7	9.6-9.8	0.09	17.7	17.2-18.6	0.72
	0.75	8.9	8.0-10.1	0.98	16.9	16.2-17.4	0.58
	1.00	8.0	7.8-8.3	0.23	15.8	15.3-16.0	0.35
Nov 2	0.25	8.8	-----	---	16.2	-------	----
	0.75	7.2	-----	---	15.3	-------	----
	1.00	4.0	-----	---	14.5	-------	----

Table 3. DO and temperatures from bottom water samples from Pond 2, 1983.

Date	Depth (m)	Dissolved Oxygen (mg/l) Mean	Range	sd	Temperature (°C) Mean	Range	sd
Jul 1	0.25	7.8	6.3-9.7	1.41	31.3	30.0-33.0	1.51
	0.50	5.9	2.4-8.3	2.57	30.5	-------	---
	0.75	2.4	1.6-3.5	0.91	29.9	29.0-30.5	0.72
	1.00	1.3	0.4-1.8	0.63	27.9	27.0-28.5	0.72
Jul 15	0.25	11.3	9.8-12.4	0.88	28.3	27.9-28.6	0.38
	0.50	11.3	10.2-12.0	0.75	27.8	26.7-28.3	0.83
	0.75	10.1	8.9-11.2	1.04	27.6	27.0-28.2	0.67
	1.00	6.1	5.4-6.7	0.56	27.2	26.8-28.0	0.65
Jul 28	0.25	10.7	7.1-13.4	2.86	32.0	30.8-33.0	1.43
	0.50	6.9	5.6-8.8	1.37	30.3	28.4-31.2	1.03
	0.75	1.9	1.3-3.2	0.87	28.6	28.3-28.8	0.25
	1.00	0.1	0.0-0.3	0.13	28.0	27.7-28.2	0.30
Aug 12	0.25	12.3	11.4-12.8	0.62	29.7	29.0-30.4	0.75
	0.50	8.5	6.1-10.1	1.84	28.5	27.9-29.1	0.70
	0.75	4.2	3.5-5.9	1.09	27.0	26.4-27.4	0.49
	1.00	0.8	0.2-1.4	0.48	26.1	25.8-26.2	0.23
Aug 31	0.25	13.2	9.7-14.6	2.38	30.5	29.0-31.4	1.17
	0.50	6.9	5.5-7.6	0.91	28.3	28.1-28.8	0.38
	0.75	1.7	0.3-3.0	1.11	27.2	27.0-27.3	0.15
	1.00	1.5	0.2-3.0	0.48	26.1	25.8-26.2	0.23
Sep 28	0.25	9.4	7.6-12.6	2.26	24.6	23.5-26.0	1.26
	0.50	8.5	5.2-9.7	2.16	23.7	22.9-24.2	0.66
	0.75	4.1	2.1-6.1	1.63	22.3	22.0-22.6	0.29
	1.00	3.1	0.6-5.1	1.86	22.0	21.1-23.0	0.89
Nov 16	0.25	12.8	-----	---	6.5	-------	---
	0.50	12.4	-----	---	6.3	-------	---
	0.75	12.0	-----	---	6.2	-------	---
	1.00	11.6	-----	---	5.8	-------	---

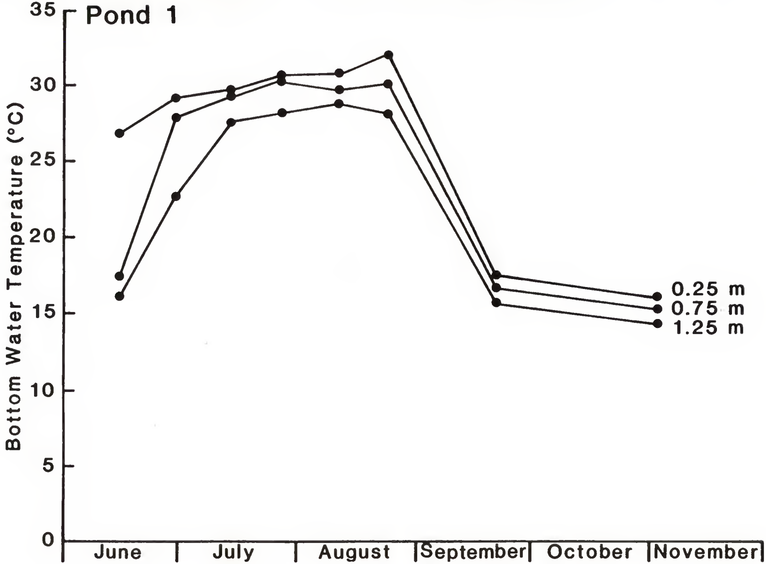

Figure 5. Temperatures measured from bottom water samples collected from Pond 1, 1983.

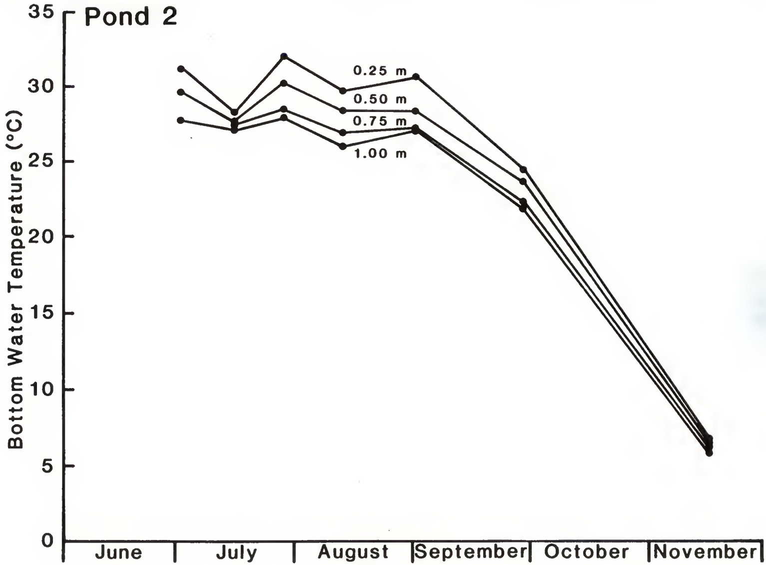

Figure 6. Temperatures measured from bottom water samples collected from Pond 2, 1983.

We believe that the early summer population increases evident on Figures 7 and 8 to be an artifact of our sampling procedure. Larger crayfish appear to have been sampled more effectively with our equipment. The YOY crayfish should have all been independent by the time our sampling commenced, but the smallest ones may have been pushed in the mud when the dip net was used. The low water levels present in both ponds is believed to have prevented any mass movements of crayfish either into or out from them.

Using the SAS statistical analysis package (SAS Institute Inc. 1982) we looked for evidence of a relationship between the distribution of crayfish within the two ponds and the environmental parameters we measured,(DO, water temperature, secchi disc transparencies, and water level). We also sought any relationship with the time of the year the samples were taken. Of all of these independent variables a significant corelation with observed crayfish distribution could only be found for DO levels. Since we considered DO to affect distribution in a stepwise rather than a gradient fashion the Proc LOGIST function of the SAS package was used. This test showed that at a 90% confidence level, 91% of the time the presence of crayfish in a 1 m^2 area of the bottom of Pond 1 could be successively predicted using a model based on DO measurements from bottom water samples. 84% of the time the presence of absence of crayfish on the bottom of Pond 2 could be predicted on the basis of DO level in bottom water samples and oxygen profiles from the oxygen meter (Tables 6-7). Figure 9 shows that crayfish were much more likely to be present once DO levels reached 2.5mg/l or higher.

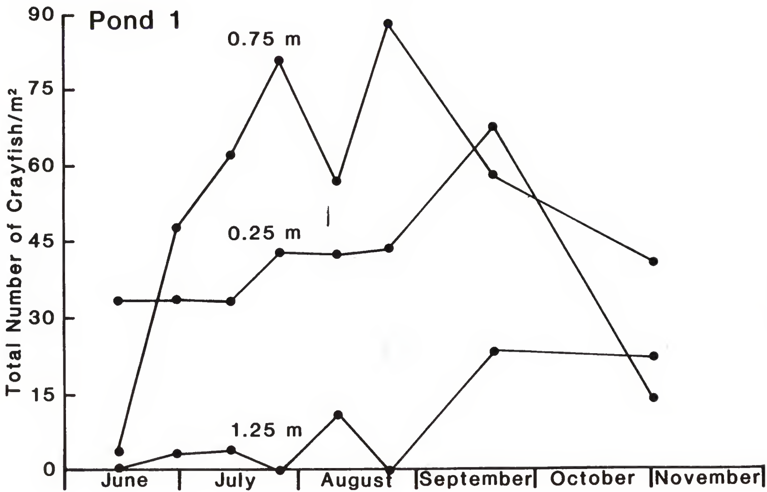

Figure 7. Density of crayfish measured at different depths in Pond 1, 1983.

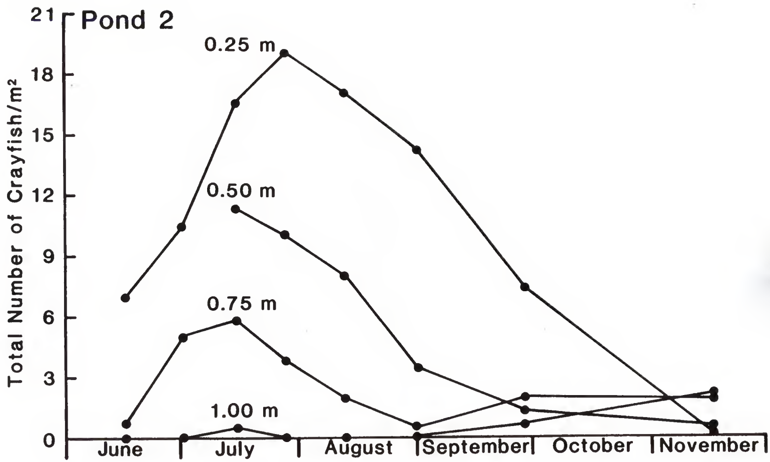

Figure 8. Density of crayfish measured at different depths in Pond 2, 1983.

Table 4. Crayfish Density per square meter in Pond 1, 1983.

		Young of Year			Adults			Total
Date	Depth	Avg/m^2	Range	sd	Avg/m^2	Range	sd	Avg/m^2
Jun 15	0.25	29.6	0-96	36.71	4.3	2-8	2.00	33.9
	0.75	2.1	0-9	3.37	2.3	0-5	1.91	4.4
	1.25	0.0	---	---	0.3	0-1	0.53	0.3
Jun 30	0.25	33.6	23-46	10.40	0.3	0-1	0.53	33.9
	0.75	47.9	12-74	25.81	2.0	0-8	3.18	49.9
	1.25	2.8	0-18	7.14	0.9	0-2	0.95	3.7
Jul 14	0.25	32.5	13-62	17.67	0.8	0-2	1.13	33.3
	0.75	59.3	22-149	49.01	3.5	1-6	2.02	62.8
	1.25	3.8	0-16	6.10	0.3	0-1	0.53	4.1
Jul 27	0.25	42.1	16-59	19.04	1.6	0-6	2.37	43.7
	0.75	78.1	15-125	42.51	3.9	0-7	2.55	82.0
	1.25	0.0	---	---	0.0	---	---	0.0
Aug 11	0.25	41.8	20-69	16,93	2.1	0-4	1.77	43.9
	0.75	60.3	16-117	36.16	1.1	0-2	0.73	61.4
	1.25	11.0	1-26	11.97	0.5	0-4	1.61	11.5
Aug 24	0.25	42.8	15-87	28.38	1.0	0-5	2.02	43.8
	0.75	86.0	64-128	32.29	3.1	1-5	1.67	89.1
	1.25	0.0	---	---	0.0	---	---	0.0
Sep 21	0.25	67.4	48-83	12.30	1.1	0-4	1.55	68.5
	0.75	56.8	34-87	18.87	1.6	1-5	1.61	58.4
	1.00	23.0	11-52	14.91	0.9	0-2	1.13	23.9
Nov 2	0.25	12.9	5-24	6.71	0.0	---	---	12.9
	0.75	40.6	22-55	12.91	0.6	0-2	1.05	41.2
	1.00	21.3	2-49	16.97	0.3	0-1	0.53	21.6

Table 5. Crayfish Density per square meter in Pond 2, 1983.

Date	Depth	Young of Year			Adults			Total
		Avg/m^2	Range	sd	Avg/m^2	Range	sd	Avg/m^2
Jun 16	0.25	0.9	1-4	1.55	6.0	0-28	11.02	6.90
	0.75	0.4	0-2	0.85	0.4	0-1	0.59	0.8
	1.00	0.0	---	---	0.0	---	---	0.0
Jul 1	0.25	9.1	2-27	9.14	1.4	0-6	2.37	10.5
	0.75	3.8	3-11	3.70	1.5	0-6	2.29	5.8
	1.00	0.0	---	---	0.0	---	---	0.0
Jul 15	0.25	14.0	2-29	10.59	1.8	0-4	1.81	15.8
	0.50	9.6	2-23	7.97	1.1	0-4	1.67	10.7
	0.75	4.9	0-10	4.71	1.0	0-4	1.61	5.9
	1.00	0.6	0-3	1.36	0.0	---	---	0.6
Jul 28	0.25	18.1	4-43	14.54	1.0	0-4	1.50	19.1
	0.50	9.1	0-18	6.45	1.0	0-3	1.37	10.1
	0.75	3.5	0-6	3.77	0.4	0-1	0.59	3.9
	1.00	0.0	---	---	0.0	---	---	0.0
Aug 12	0.25	16.6	9-40	14.25	0.0	---	---	16.6
	0.50	7.3	0-10	5.18	0.8	0-2	1.02	8.1
	0.75	2.1	0-7	2.89	0.0	---	---	2.1
	1.00	0.0	---	---	0.0	---	---	0.0
Aug 31	0.25	14.3	6-31	10.89	0.0	---	---	14.3
	0.50	3.8	0-6	2.34	0.0	---	---	3.8
	0.75	0.5	0-3	1.22	0.0	---	---	0.5
	1.00	0.0	---	---	0.0	---	---	0.0
Sep 28	0.25	6.6	1-15	5.18	0.0	---	---	6.6
	0.50	1.6	0-6	2.37	0.0	---	---	1.6
	0.75	1.9	1-5	1.67	0.3	0-1	---	2.2
	1.00	0.8	0-2	1.02	0.0	---	---	0.8
Nov 16	0.25	0.3	0-1	---	0.0	---	---	0.3
	0.50	0.5	0-1	0.61	0.3	0-1	---	0.8
	0.75	1.6	0-4	1.93	0.3	0-1	---	1.9
	1.00	2.1	0-4	1.55	0.0	---	---	2.1

DISCUSSION

Researchers have studied the distribution of crayfish found in many habitats. Merkle (1969) and Hazlett, Rittschoff, and Ameyaw-Akumfi (1979) studied the distribution of O. juvenalis and O. virilis respectively in streams. Merkle (1969) observed that 5 crayfish remained in the same location over a 30 hr. time span. Hazlett et al. (1979) concluded crayfish utilize only a small fraction of the total environment available to them.

Mobberly and Pfrimmer (1966) examining a population of crayfish found in a ditch noted these animals moved more than those studied in streams. The crayfish they studied moved throughout the 21m long ditch. There was a general trend of movement toward the deeper end of the ditch.

Other researchers have studied crayfish found in ponds. Camougis and Hichar (1959) observed little evidence of home ranges or territories utilized by the crayfish they studied, and concluded they moved freely over the bottom. Our catch results indicate crayfish in the two ponds we studied also moved freely over the bottom. All of our sampling over the entire 6 month study was done at approximately the same locations each time. If the crayfish found in these ponds had restricted movements, it would have been expected that the number of crayfish caught at any given location would decrease with repeated sampling. Figures 7 and 8 show this was not the case.

Tack (1942), Jackson (1972) and Flint (1977) observed crayfish moving into deeper water in the fall. This seasonal migration of crayfish was observed in our study. Figure 8 shows this to be especially true for Pond 2. All throughout the first 7 sampling periods, the majority of crayfish caught in this pond were collected from the shallowest belt

Table 6. Statistical analysis of crayfish occurrance vs. DO in Pond 1, 1983.

Stepwise Logistic Regression Procedure

Dependent variable: crayfish occurrance

192 observations

27 observations having no crayfish present

165 with crayfish present

Variable	Mean	Minimum	Maximum	Range
Bottom water DO	6.12	0.1	10.1	10
Probe DO	2.61	0.2	8.2	8

Final Parameter Estimates

Variable	Beta	sd	chi^2	P	R
Intercept	-4.00	1.00	15.96	.0001	
Bottom Water DO	1.35	0.26	25.25	.0000	.386

Fraction of concordant pairs of predicted probabilities and responses: 0.937

Rank correlation between predicted probability and response: 0.896

Table 7. Statistical analysis of crayfish occurrance vs. DO in Pond 2, 1983.

Stepwise Logistic Regression Procedure

Dependent variable: crayfish occurrance

216 observations

73 observations having no crayfish present

143 with crayfish present

Variable	Mean	Minimum	Maximum	Range
Bottom water DO	7.16	0.0	14.6	14.6
Probe DO	3.01	0.2	11.6	11.4

Final Parameter Estimates

Variable	Beta	sd	chi^2	P	R
Intercept	-1.21	0.31	14.68	0.0001	
Bottom Water DO	0.49	0.08	39.74	0.0000	0.37
Probe DO	-0.38	0.07	25.92	0.0000	-0.29

Fraction of concordant pairs of predicted probabilities and responses: 0.827

Rank correlation between predicted probability and response: 0.664

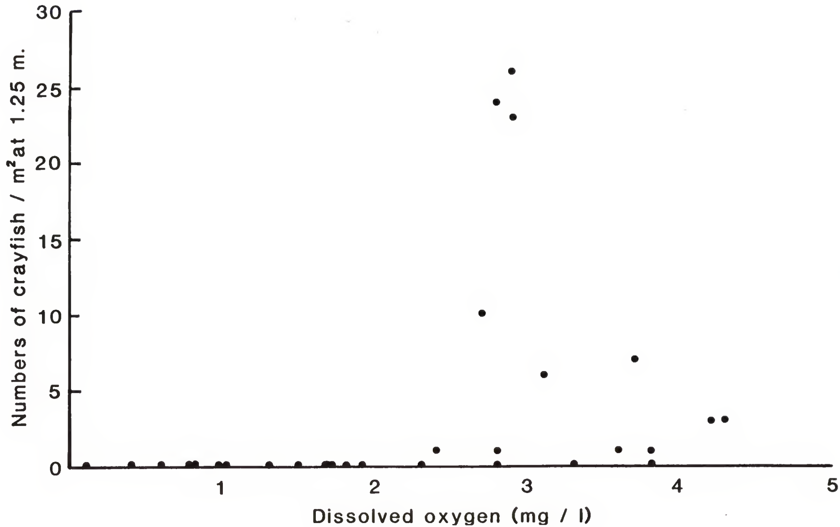

Figure 9. Density of crayfish at 1.25m in Pond 1 vs. dissolved oxygen levels.

sampled. This trend was completely reversed when this pond was sampled in November, the great majority of crayfish being caught from the deepest two contours.

Many studies have been done examining the lower range of DO tolerated by crayfish. Avault et al. (1974) recommend 3mg/l for crayfish culture ponds and considered 1 mg/l to be dangerously low. Melancon and Avault (1976) determined the 96hr LC_{50} for crayfish 9-12mm total length to be 0.75- 1.1mg/l. These authors also noted that crayfish are most susceptible to low DO when they are molting.

Other researchers working in laboratories also investigated in detail the oxygen partial pressure (P_{O_2}) requirements and metabolic rates of crayfish. Taylor and Wheatly (1980) concluded the crayfish _Austropotamobius pallipes_ migrated from water once the P_{O_2} dropped to 42mmHg (2.0 mg/l) or lower. Despite the low DO levels present in the ponds we studied, especially Pond 2, we never observed any crayfish out of the water around either pond. McMahon, Burggren, and Wilkens (1974) concluded that _O. virilis_ died following prolonged exposures of P_{O_2} of 30mmHg (1.8mg/l).

Our trapping results are in agreement with those stated above. Often sampling one of the two ponds we would collect large numbers of crayfish at one contour, but sampling the next deepest one we would not collect _any_. We repeatedly measured the oxygen levels present at this deeper contour (1.25m Pond 1, 1.00m Pond 2) to be below the 2.5mg/l threshold evident in Figure 9.

Other studies examined the inter and intra-specific distribution of crayfish with regards to DO. Wiens and Armitage (1961) provided evidence that a synergistic realtionship between low DO and high temperature

increased mortality. They concluded that O. nais can not inhabit intermittently full ditches because this crayfish is incapable of maintaining its metabolic rate under stress. Fast and Momot (1973) studied the distribution of the crayfish O. virilis within a stratified lake. They found that adult male crayfish were concentrated in the shallower water, and appear to have been forcing female crayfish into deeper, cooler water. Once this lake was artificially destratified, they found crayfish of both sexes to be evenly distributed throughout the lake in water 10C or warmer.

In our study we found a statistically significant relationship between bottom water DO levels and presence or absence of crayfish. We believe that the seasonal changes in crayfish distribution observed in the ponds we studied were related at least in part to the DO levels present. After the ponds underwent late summer turnover DO levels found at the deeper depths increased. This increase in DO was correlated with the large numbers of crayfish found in deeper water after the turnover.

Studies have also shown that crayfish demonstrate little activity once water temperatures drop below 10C. Jackson (1972) noted that O. nais was very inactive once water temperature dropped below 8C and moved only when touched at 4C. We observed similiar inactivity in our November sampling of our two ponds.

We found no significant relationship between temperature and crayfish distribution in this study. Cincotta (1979) noted that up to 30-33c crayfish preferred water warmer than that they had been acclimated in. Above that range of temperature the opposite was true. Such a relationship may have been present if we had sampled the two ponds over a longer period of time. We observed the migration to deeper water in late

summer, but it would be difficult to determine whether this was in response to bottom water temperatures or DO levels, light levels or an interaction between a combination of these factors.

With the high densities of crayfish found in Pond 1, density dependent agression described by Bovbjerg and Stephen (1971) may have been a factor affecting crayfish distribution. Any structure found in the ponds could allow for greater spacing of the crayfish present compared to the two dimensional surface of the pond bottom. Crayfish using structure could lead to higher densities at these locations. Loring and Hill (1976) observed that O. causeyi acclimated at 14,19, and 29C selected shelter over open area as long as it was present in water between 14-29C. Flint and Goldman (1977) examining crayfish distribution in Lake Tahoe found twice as many crayfish along one transect area covered with small stones and large cobbles as compared to two other unstructured sites. Aiken (1967) found that since O. virilis had not developed physiological means to survive freezing, its winter survival in streams was dependent on remaining in rocky areas that did not freeze to the bottom. Jackson believed that crayfish in his small ponds may move to deeper water in the fall to escape being frozen in shallower areas.

Little structure was present in the two ponds we studied once we had removed the rocks and branches found in shallower water. Macrophytic plant growth was absent from both ponds from the start of the study. Some crayfish provide their own structure by burrowing. Questions remain concerning the extent to which O. nais burrows. Jackson (1972) found burrows in the ponds he studied, but was unable to remove crayfish from them. Hobbs (1942) stated that members of the genus Orconectes found in Florida did not include primary (restricted to burrows) or secondary burrowers (move from burrows during the rainy season).

During preliminary research for this study done in April, seinings of Pond 2 collected crayfish having a dirty longitudinal lateral band running the length of their carapace and abdomen even with their eyes. This indicates that these crayfish may have recently been lying in the bottom mud of the pond to this level. This is the only evidence we observed of any burrowing behavior of any type. Aiken (1967) noted similiar behavior in overwintering O. virilis. During the daytime O. nais clearly utilized available cover in the two ponds we studied. They were commonly present under rocks, and small YOY even appeared to utilize depressions from cattle hoof prints as cover.

In conclusion, we found bottom water DO to provide a significant relationship with the distribution of crayfish found in the two ponds we studied. The seasonal changes in crayfish distribution we observed may be due to fluctuations in DO levels found in deeper water. Leaving shallower water in colder weather would also appear to have survival value to crayfish. They avoid being frozen, and while they are inactive in the cold water they are less accessible to some of their predators.

Our consistent catch results indicated that the crayfish of these ponds moved freely over the bottom rather than having restricted home ranges. Structure sites used in another study (Paper 4) did serve to concentrate crayfish at their locations.

This study and others will continue to gather further information concerning the life histories of crayfish found in Kansas. Such information will prove useful if culture of these crayfish is undertaken. It will also be important in determining the effects of introduction of new species of crayfish into the state.

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Paper 3: QUANTITATIVE TECHNIQUE FOR CRAYFISH SAMPLING

INTRODUCTION

Crayfish are cultured extensively in the southern United States. They have value both for human food and as fish bait. Crayfish are common in Kansas farm ponds, but little is known of the species found in them. A quantitative sampling method would be valuable in a study of these crayfish.

The purpose of this paper is to describe a quantitative sampling method to capture crayfish from ponds. Baited traps and seines have been used with limited success in estimating the size of crayfish populations (Momot 1967). Malley and Reynolds (1978), Jackson (1972), and Daniels (1980) have noted that baited traps are not well suited for quantitiative sampling of crayfish. The larger more aggressive crayfish may either exclude the smaller ones from the traps altogether, or eat them if they do get into the traps. In small ponds mark-recapture studies are used in conjunction with baited traps or nets to estimate population size (Jackson 1972). Such mark recapture studies must be of short duration since permanent marking of crayfish is impreactical if not impossible (Jackson 1972).

The quantitative nature of the sampling technique we used enabled us to determine the density gradients and to relate the distribution of crayfish found within a pond to environmental parameters including dissolved oxygen and water temperature.

DESCRIPTION OF EQUIPMENT

We developed two open-ended box traps. These traps gave us a quantitative element that could not be provided easily by other sampling methods. The traps were constructed using 1.3cm (1/2 inch) angle iron which was welded to form frames. The trap sides of 6.5mm (1/4 inch) hardware cloth were wired onto the sides of the traps. The open ends of the traps were $1m^2$, one trap being 1.03m (3ft 5inches)) tall, the other, 1.35m (4ft 5inches). the two traps weighed 11.3 and 14.5 kgs respectively. The traps were carried into position by two people like a stretcher using detachable 1.82m (6 ft) lengths of 1.3cm (1/2 inch) conduit pipe for the handles. These handles were inserted into 3/4 inch conduit wired onto the sides of the trap. To remove crayfish from the trap we constructed a long-handled dip net 71cm (28 inches) wide by 46cm (18 inches) high of 3.2mm (1/8 inch) mesh. An example of these traps is illustrated in Figure 1.

In use, a trap was picked up and moved perpendicular from shore to the desired depth. While moving it into position, the trap was carried well above water and oriented so its handles were parallel to shore. Once at the right depth, the trap was quickly lowered, and pushed into the mud bottom of the pond, effectively sampling an area of $1m^2$. Crayfish inside the trap were scooped out with the net. To avoid collecting large amounts of mud, the net was skipped lightly over the pond bottom. The 1.03m tall trap was used in water up to 0.75m deep, the 1.35m tall trap was used in water up to 1.25m.

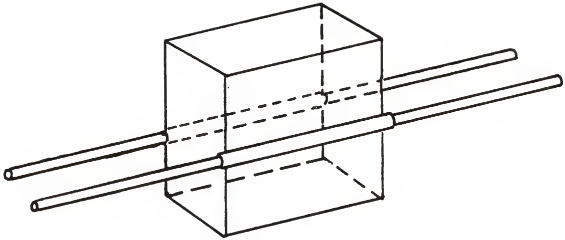

Figure 1. Open-ended box trap used for crayfish sampling.

EVALUATION

The pond used to test the traps was typical of pasture ponds found in the Flint Hills region of Kansas. When the traps were tested, the pond had an area ot 0.305ha, and a maximum depth of 1.7m.

The trapping efficiency of this technique was tested using marked crayfish. The hind leg clips used for these marks were readily identifiable but were unlikely to hinder the movement of the animals. Five marked crayfish were placed into the trap which was already positioned on the botton. The dip net was used in sweeps from one end of the trap to the other, alternating from the side of the trap closer to shore to the side opposite. The number of sweeps needed to recapture all five of the marked crayfish was recorded.

The above test was repeated three times. In one test seven sweeps were needed to remove all five crayfish. In the other two tests only 4 sweeps were needed to recapture the marked crayfish. Although the trap was placed on the bottom without using the conduit handles, unmarked crayfish were also collected in these tests.

Next the traps were used to sample the pond at seven transects around the pond at both 1/2 and 1m depths. The trap was swept ten times at each location. The number of crayfish collected each sweep was noted. At two sites crayfish were collected at the sixth sweep or later, (9,10). At the other 12 sites, no crayfish were collected after the fifth sweep.

On the basis of the results of these tests, a standardized sampling technique was developed. After the sixth sweep once two consecutive sweeps were empty, sampling at that site was considered complete.

DISCUSSION

The trapping technique described in this paper is not new, it has been used in the past for sampling larval fish (Kjelson,Turner, and Johnson 1975). The use of this technique eliminates the problems described above. We assume that since the trap is suspended above water between the 1.8m conduit handles up to the moment it is set, the crayfish beneath it are unaware of its presence and remain undisturbed. This assumption is strengthened by the fact that fathead minnows, Pimephales promelas, were also collected from within the trap on many occasions. By using the trap in a sampling scheme based on a contour map of the pond being studied, population estimates of crayfish at different depths of the pond can be derived.

This sampling technique is not without some potential difficulties. Crayfish might be pushed into the mud by the edge of the trap or by the dip net itself. Except for very small crayfish, (probably less than 10mm carapace length), we believe that it is unlikely that these crayfish would remain stuck in the mud the entire length of time the site was being sampled. Sampling deeper sites allows the crayfish within the trap more climbing surface (the sides of the trap) to escape the net. Sampling at the deeper contours often required more sweeps, but seldom more than 12, because of crayfish being up on the sides of the trap.

In addition to providing a means for quantitative sampling, these traps sampled discrete areas. This allowed us to attempt to relate the observed distribution of crayfish with dissolved oxygen levels and water temperatures measured from bottom water samples.

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Paper 4: THE EFFECTS OF STOCKING DENSITY, ADDED FOOD, AND STRUCTURE ON THE GROWTH AND DISTRIBUTION OF THE CRAYFISH *Orconectes nais*

INTRODUCTION

During the summers of 1982 and 1983 we undertook a study of the growth and distribution of the crayfish *Orconectes nais*. This species is common over wide areas of the central United States west of the Mississippi River (Williams and Leonard 1952), and is found in many Kansas farm ponds. Although they are not as yet specifically cultured for either food or fish bait in Kansas, they are often harvested as an incidental crop by fish pond owners.

Crayfish culture and associated research is much further along in the southern U.S., especially in Louisiana. In their work with *Procambarus clarkii*, Huner and Avault (1976), and others, (Avault et al. 1974), (Chien and Avault 1980), have investigated many aspects of crayfish culture. Much of their work has examined the effects of stocking densities and supplemental feeding. They also studied the problems associated with low dissolved oxygen concentrations and overcrowding of crayfish in culture ponds.

As part of our study we performed two experiments on caged crayfish. In the first of these experiments (henceforth referred to as Experiment I) we attempted to establish relationships between stocking density and growth and survival of the caged crayfish. In the second experiment (Experiment II) we desired to determine the effects of additional food and/or structure on the growth and survival of crayfish stocked at equal densities.

The third experiment (Experiment III) also involved the used of additional structure. In this study we placed structure clusters along the 1/2m deep contour of the open pond. We then used the box trap described in Paper Three of this thesis to sample over and between the structure clusters. We were interested to see to what extent the structure would concentrate the crayfish of the pond.

METHODS

The pond used in this phase of our study was an older, eutrophic farm pond. When full the pond had a maximum depth of 1.4m and an area of 0.717ha.

The four cages used in Experiments I and II were square, with an area of $4m^2$. They were constructed of 6.4mm (1/4 inch) hardware cloth. The same material was used to make partitions dividing each cage into $4\text{-}1m^2$ quadrants. After they were constructed, they were placed in the pond 10 m apart in water 1/2 m deep and pushed into the mud bottom. Steel fence posts were pounded into the pond bottom alongside the corners of each cage. The corners of the cage were then tied onto the posts to anchor it in position.

Barbed wire was attached to the top of the fence posts to discourage cows from pushing the cages over. The wire may have also kept the cattle from getting close enough to the cage to allow the crayfish inside to escape by way of their hoof prints. We used a dip net to scoop out any crayfish inadvertly trapped within the cage when it was put down. A hardware cloth cover was wired on over the top of each cage.

In Experiment I the treatments used in each cage were four different stocking densities: $2/m^2$, $4/m^2$, $8/m^2$, and $16/m^2$. Each treatment was positioned in each of the four quadrants once, as per a latin square design (Figure 1). The crayfish stocked were all adults, one-half of the crayfish stocked in each quadrant were males and one-half females (Table 1). All of the crayfish used in the cage experiments were either in the late stages of metecdysis,(termed stage C by Stevenson 1968), or intermolt.

All of the crayfish in a particular quadrant were marked with a leg clip unique to that quadrant. This enabled us to detect invasion of pond crayfish or escape into other compartments during the course of the 4 week experiment. We also watched to see if regeneration of individual leg clips occurrd during the course of this experiment.

Before being stocked each of the crayfish were measured for initial dorsal carapace length. Venier clapiers were used and these measurements were made to the nearest 0.1 mm. There were no significant differences between the starting lengths of the crayfish used in the four treatments of this experiment. At the end of the experiment, the crayfish were removed from the cages and remeasured. In this experiment, growth of crayfish within each quadrant was defined as average final length minus the average initial length. Averaging was necessary because mortality occurred over the course of the experiment and the crayfish were not individually marked.

The same four cages used in Experiment I were reused in Experiment II. In this experiment, 25 young of the year crayfish (13 males, 12 females) were stocked in each quadrant. The four treatments used were different combinations of supplemental food and artificial structure:

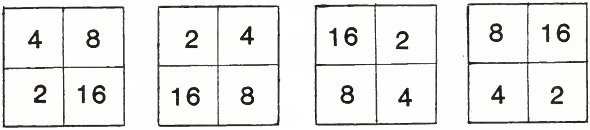

Figure 1. Treatment arrangement for Experiment I. Numbers represent crayfish stocked per square meter.

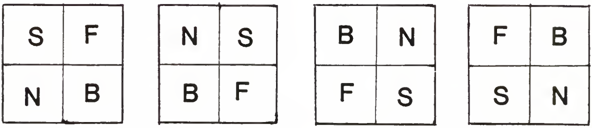

Figure 2. Treatment arrangement for Experiment II. Letters represent the following: N=neither structure nor food added, S=structure only added, F=food only added, and B=Both food and structure added.

Table 1. Results of Experiment I; Effects of stocking density on the growth and survival of caged crayfish.

Quadrants stocked at 2 crayfish per square meter

Cage	Numbers			%Reg*	Average CL (mm)			Total Weight(g)			Average Weight(g)		
	Start	End	%Surv		Start	End	Gain	Start	End	Gain	Start	End	Gain
1	2	2	100	100	32.3	34.4	2.1	17.6	21.7	4.1	8.8	10.9	2.1
2	2	2	100	100	33.7	35.2	1.5	20.6	23.7	3.1	10.3	11.9	1.6
3	2	0	0	---	33.1	---	---	19.1	0.0	-19.1	9.6	---	---
4	2	1	50	100	34.7	35.2	0.5	22.4	11.8	-10.6	11.2	11.8	0.6
av	2	1	63	100	33.5	34.9	1.4	19.9	14.3	-5.6	10.0	11.5	1.5

Quadrants stocked at 4 crayfish per square meter

Cage	Numbers			%Reg	Average CL (mm)			Total Weight(g)			Average Weight(g)		
	Start	End	%Surv		Start	End	Gain	Start	End	Gain	Start	End	Gain
1	4	4	100	75	32.6	32.9	0.3	36.6	37.6	1.0	9.2	9.4	0.2
2	4	3	75	100	32.7	35.0	2.3	37.5	34.8	-2.7	9.4	11.6	2.2
3	4	3	75	33	34.6	36.6	2.0	44.5	40.6	-3.9	11.1	13.5	2.4
4	4	3	75	100	32.4	36.0	3.6	36.2	38.6	2.4	9.1	12.9	3.8
av	4	3	81	77	33.1	35.1	2.0	38.7	37.9	-0.8	9.7	11.9	2.2

Quadrants stocked at 8 crayfish per square meter

Cage	Numbers			%Reg	Average CL (mm)			Total Weight(g)			Average Weight(g)		
	Start	End	%Surv		Start	End	Gain	Start	End	Gain	Start	End	Gain
1	8	5	63	60	32.8	33.5	0.7	75.6	50.4	-25.2	9.5	10.1	0.6
2	8	5	63	60	33.6	34.4	0.8	80.7	55.0	-25.7	10.1	11.0	0.9
3	8	5	63	80	32.8	33.7	0.9	75.3	51.4	-23.9	9.4	10.3	0.9
4	8	8	100	75	31.7	33.0	1.3	66.1	75.2	9.1	8.3	9.4	1.1
av	8	6	72	69	32.7	33.7	1.0	74.4	58.0	-16.4	9.3	10.2	0.9

Quadrants stocked at 16 crayfish per square meter

Cage	Numbers			%Reg	Average CL (mm)			Total Weight(g)			Average Weight(g)		
	Start	End	%Surv		Start	End	Gain	Start	End	Gain	Start	End	Gain
1	16	9	56	56	33.3	33.9	0.6	158.4	93.5	-64.9	9.3	10.4	1.1
2	16	12	75	67	32.5	33.2	0.7	165.6	117.4	-48.2	10.4	9.8	-0.6
3	16	5	31	80	32.3	33.7	1.4	142.4	51.5	-90.9	8.9	10.3	1.4
4	16	13	81	92	33.1	33.5	0.4	154.9	131.3	-23.6	9.7	10.1	0.4
av	16	10	61	74	32.8	33.6	0.8	155.3	98.4	-56.9	9.6	10.2	0.6

* Percentage of surviving crayfish that showed regeneration of leg clip.

artificial structure only, supplemental feeding only, both food and structure, and neither one added (Figure 2). These four treatments were rotated through the 4 quadrants in the same fashion as they were in Experiment I.

The food used was diced bluegill, Lepomis macrochirus. The crayfish were fed 25% of their wet weight three times per week in wet food. During the five week duration of this test, feedings were increased in amount each week based on projected weight gains by the crayfish (Table 7).

The clusters of artificial structure were composed of 5-30.5cm (one foot) long sections of 10.2cm (4 inch) diameter clay drain tile. Three of the tile sections were set side by side each other with their ends lined up. The other two tile sections were laid across the open ends of the group of three tiles (Figure 3).

The crayfish of different treatments had different legs clipped of at the base of the tibia. Initial carapace lengths of the crayfish stocked were measured as in Experiment I (Table 2). After 5 weeks the crayfish were removed from the cages and returned to the lab. At the lab their carapace length was remeasured and their marks checked to see if crayfish had moved from one quadrant to another within the same cage. There never was any evidence of burrowing found along the botton edge of any of the cages during either Experiment I or II.

In Experiment III, the same tile structure clusters described above were used in the open water of the pond at a depth of 1/2m. On July 7, 1983, we positioned 8 structure sites 20 m apart from each other around the pond . The locations of the structure sites were marked with sticks pushed into the pond bottom immediately adjacent to the sites. On August 17, 1983, (41days later) we sampled over each structure site and midway

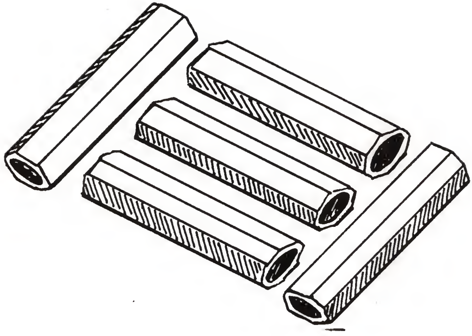

Figure 3. Arrangement of clay drain tiles used for structure in Experiments II and III.

Table 2. Results of Experiment II; Effects of additional food and structure on the growth and survival of caged crayfish.

No additional food or structure

Cage	Numbers			Average CL (mm)			Total weight(g)			Average weight(g)		
	Start	End	%Surv	Start	End	Gain	Start	End	Gain	Start	End	Gain
1	25	16	64	29.1	32.5	3.4	161.4	146.0	-15.4	6.5	9.1	2.6
2	25	18	72	27.9	31.9	1.2	146.2	157.2	11.0	5.8	8.7	2.9
3	25	13	52	29.6	32.9	3.3	176.2	124.8	-51.4	7.0	9.6	2.6
4	25	7	38	29.3	32.9	3.6	167.5	68.9	-98.6	6.7	9.8	3.1
Avg	25	14	54	29.0	32.6	3.6	162.8	124.2	-38.6	6.5	9.3	2.8

Additional structure only

Cage	Numbers			Average CL (mm)			Total weight(g)			Average weight(g)		
	Start	End	%Surv	Start	End	Gain	Start	End	Gain	Start	End	Gain
1	25	25	100	30.0	34.8	4.8	184.5	291.4	107.0	7.4	11.7	4.3
2	25	22	88	30.3	34.0	3.7	184.4	241.3	56.8	7.4	11.0	3.6
3	25	24	96	30.2	34.6	4.4	180.5	270.8	90.3	7.2	11.3	4.1
4	25	5	20	29.0	32.0	3.0	162.8	43.9	-118.9	6.5	8.8	2.3
Avg	25	19	76	29.9	33.9	4.0	178.1	211.9	33.8	7.1	10.7	3.6

Additonal food only

Cage	Numbers			Average CL (mm)			Total weight(g)			Average weight(g)		
	Start	End	%Surv	Start	End	Gain	Start	End	Gain	Start	End	Gain
1	25	16	64	28.9	35.0	6.1	165.6	188.4	22.9	6.6	11.8	5.2
2	25	24	96	29.4	34.6	5.2	170.1	279.6	109.5	6.8	11.6	4.8
3	25	14	56	29.1	33.7	4.6	163.1	145.6	-17.5	6.5	10.4	3.9
4	25	15	60	29.4	34.7	5.3	170.0	172.9	2.9	6.8	11.5	4.7
Avg	25	17	69	29.2	34.5	5.3	167.2	196.6	29.5	6.7	11.3	4.7

Both additional food and structure

Cage	Numbers			Average CL (mm)			Total weight(g)			Average weight(g)		
	Start	End	%Surv	Start	End	Gain	Start	End	Gain	Start	End	Gain
1	25	22	88	29.0	34,3	5.3	170.0	248.0	78.0	6.8	11.3	4.5
2	25	20	80	29.3	33.9	4.6	164.7	214.1	49.4	6.6	10.7	4.1
3	25	21	84	29.9	34.8	4.9	178.9	243.8	64.9	7.1	11.6	4.1
4	25	21	84	28.4	33.4	5.0	150.4	211.4	61.0	6.6	10.9	4.3
Avg	25	21	84	29.2	34.1	5.0	166.0	229.3	63.3	6.6	10.9	4.3

between them with our $1m^2$ box drop trap. When the trap was in place over a structure site, the tiles of the structure were pulled loose from the bottom and shook vigorously and removed. We then scooped any crayfish present in the trap using a dip net.

Because the difference in crayfish densities was not as great as anticipated, we thought that low oxygen levels may have prevented crayfish from utilizing the structure sites this first trial. We repeated this experiment setting the structure October 4, and sampling it for crayfish as described above on October 25 (21 days later).

RESULTS

The statistical analysis required for this study was done with the aid of the SAS statistics package. In Experiment 1, there was no significant difference ($pr < 0.5$) in growth between stocking treatments. As another means to compare growth rates, we looked for the initiation of regeneration on the limb amputated for the leg clip. Stevenson and Henry (1971) found that no growth of clipped limbs took place between molts. We then assumed that if regeneration was observed in the clipped limbs of a caged crayfish, that particular crayfish had molted at least once during the four week test. Lack of a difference in growth was also indicated by no difference in estimated molting frequency between treatments. There was no significant difference in growth between sexes of crayfish and no interaction between treatment and sex. Neither the cage nor the particular quadrant of the cage crayfish were placed in had a significant effect on their growth.

In this experiment, the treatment the crayfish were in and their sex had no significant effect on their survival. Again there was no

significant interaction between these two variables. The quadrant of the cage the crayfish were in had no significant effect on crayfish survival. There were significant differences in survival between cages ($F = 4.14$, pr $> F = 0.0082$). Cage #3 had significantly lower survival of its crayfish than the other three cages (Table 3).

The survival of crayfish during Experiment II was examined using a two way analysis. Food, structure, and the interaction between food and structure were the independent variables tested. Both variables were found to significantly increase crayfish survival, ($F = 6.72$ pr $= 0.0099$, $F = 17.4$ pr $= 0.0001$ for food and structure respectively, Table 4). No significant interaction between these two variables was found. Cage and quadrant both had significant effects on the survival of crayfish ($F = 14.16$ pr $= 0.0001$ and $F = 6.68$ pr $= 0.003$ respectively). Cages 3 and 4 and quadrant 1 (north-east) all had significantly greater mortality of crayfish in them than in the other cages and quadrants. The sex of crayfish had no significant effect on their survival (Table 5).

In Experiment II, the growth of the crayfish was investigated using the two-way analysis described above. When crayfish growth was examined only food had an effect on crayfish, significantly increasing their growth ($F = 29.05$ pr $> F = 0.0002$, Table 6). The presence or absence of structure had no significant effect on crayfish growth in this experiment, and no interaction between food and structure was evident. The effects of the other independent variables sex, the interaction between treatment and sex, cage and quadrant on the growth of these crayfish were also examined. None of these factors was demonstrated to have a significant effect on the growth of these crayfish.

Table 3. Factors affecting the survival of crayfish stocked at different densities.

Dependent variable: Survival

Source	df	F value	pr
Treatment	3	1.04	0.380
Sex	1	0.16	0.691
Trt x Sex	3	1.12	0.346
Cage	3	4.14	0.008
Quadrant	3	0.80	0.501
Error	106		

Cage	Survival LS Mean
1	0.737 a*
2	0.737 a
3	0.420 b
4	0.870 a

* Means followed by the same letter are not significantly different.

Table 4. Two way analysis of the effects of food and structure of the survival of caged crayfish.

Dependent variable: Survival

Source	df	F value	pr
Food	1	6.72	0.0099
Structure	1	17.40	0.0001
FoodxStruc	1	0.62	0.4305
Error	396		

Food	Surv. LS Mean	Structure	Surv. LS mean
no	0.650 a*	no	0.615 a
yes	0.765 b	yes	0.800 b

* Means followed by the same letter are not significantly different.

Table 5. Factors affecting the survival of caged crayfish in Experiment II.

Dependent variable: Survival

Source	df	F value	pr
Treatment	3	9.26	0.0001
Sex	1	0.06	0.8120
Trt x Sex	3	1.29	0.2774
Cage	3	15.33	0.0001
Quadrant	3	7.14	0.0001
Error	386		

Survival LS Means

Treatment		Cage		Quadrant	
N*	0.542 a	1	0.790 a	1	0.547 a**
S	0.760 b	2	0.847 bc	2	0.790 b
F	0.686 bc	3	0.710 bcd	3	0.720 b
B	0.838 c	4	0.480 b d	4	0.770 b

*The code for the treatments is: N=Neither food or structure present, S=Structure only present, F=food only present, B=Both food and structure present.

**Means followed by the same letter are not significantly different.

Table 6. The effects of food and structure on the growth of caged crayfish.

Dependent Variable: Growth

Source	df	F value	Pr
Food	1	29.05	0.0002
Structure	1	0.52	0.4859
Foodxstruc	1	3.70	0.7840
Error	12		

Food	Growth LSMean
no	3.89 a*
yes	5.05 b

*If the letters following the means are the same, they are not significantly different.

Food conversion ratios, (FCR), were determined for those quadrants receiving food by dividing the total amount of food supplied to each quadrant, 777grams, by the cumulatitive amount of weight gained by crayfish of a quadrant. These values are listed in Table 8. These values varied from a negative value, (net loss of weight over the test period), to a value of 7.10.

Analysis of the data from Experiment I was repeated deleting the data from cage having significantly poorer survival. Deleting this information produced no changes on the statistical results that included all cages. In Experiment II, we did not delete all data from both cages #3 and #4 since this would have involved losing half of the experiment's data when we could only conjecture at why the higher mortality existed in the first place.

The first time Experiment III was run, significantly more adult crayfish were found associated with the structure clusters than between them ($F = 5.61$ $pr = 0.0328$, Table 9). There was no such significant difference when total numbers of both juvenile and adults were considered.

The second time the above experiment was run, only YOY crayfish were collected. There were significantly more of these crayfish found associated with the structure than collected between the structure sites ($F = 10.49$ $pr = 0.006$ Table 10).

There is not enough information available to calculate the area from which these structures were concentrating crayfish. A rough approximation can be derived by comparing the numbers of crayfish caught at that depth with the number present in the cluster sites. As part of a separate study of this research this pond was sampled at 0.5m on September 28 and

Table 7. Feeding schedule for Experiment II.

<u>Quadrants fed</u>:
Cage 1, Quadrants 3, 4
Cage 2, Quadrants 1, 4
Cage 3, Quadrants 1, 2
Cage 4, Quadrants 2, 3

Week	Amount fed per qd(g)	First feeding	Second feeding	Third feeding	Total (g)
1	45	Aug 5	Aug 8	Aug 10	135
2	50	Aug 12	Aug 15	Aug 17	150
3	56	Aug 19	Aug 22	Aug 24	168
4	62	Aug 26	Aug 29	Aug 31	186
5	69	Sep 2	Sep 5	Sep 7- ended	138 777

Table 8. Food conversion rations (FCR) for Experiment II.

Quadrants only receiving food.

Cage	Starting weight(g)	Final weight(g)	Weight gained(g)	FCR
1	165.57	188.45	22.88	33.96
2	170.01	279.55	109.46	7.10
3	145.65	163.13	17.48	44.49
4	172.94	170.02	---	---

Quadrants receiving food and structure.

Cage	Starting weight(g)	Final weight(g)	Weight gained(g)	FCR
1	169.96	248.03	78.07	9.95
2	164.72	214.12	49.40	15.73
3	178.89	243.77	64.88	11.98
4	150.46	211.46	61.00	12.74

Table 9. Structure Clusters and Crayfish Distribution. First trial of structure experiment.

Dependent variable: Number of adult crayfish per m^2.

Source	df	F Value	Pr
Treatment	1	5.61	0.0328
Error	14		

Structure	Total adults LSMean
no	0.125 a*
yes	1.75 b

*If the letters following the means are the same, the values are not significantly different.

Table 10. Results from the second trial of structure experiment.

Dependent variable: total numbers of crayfish per m^2.

Source	df	F value	Pr
Treatment	1	5.61	0.0328
error	14		

Structure	Catch/m^2
No	1.000 a*
Yes	5.125 b

*If the letters following the means are the same, the values are not significantly different.

November 16. On these two dates 1.63 and 0.63 crayfish/m^2 respectively were collected. When these numbers are compared to the density of crayfish found on the structure sites 5.13/m^2, it appears that the sites concentrate over an area of between 3.1-8.1m^2.

DISCUSSION

Studies have been done analyzing the importance of cover as related to the distribution of natural crayfish populations. In their work with *Orconectes virilis*, Camougis and Hichar (1959) found that in a pond, this crayfish showed little evidence of having either home ranges or territories. They concluded these crayfish range freely over the pond bottom. Hazlett, Rittschoff, and Ameyaw-Akumfi (1979) found that adding burrows to a section of stream did not increase the numbers of crayfish found there. They concluded that *O. virilis* found in this stream restricted their movements within small subunits of the total available environment. Flint (1977) believed structure to be important as a refuge both during the winter and summer months. Williams and Leonard (1952) did not consider *O. nais* as a primary burrower. This may have been why they utilized the additional structure made available to them in Experiment III. Both Flint (1977) and Jackson (1972) comment on the inactivity of crayfish in cold water and suggest that shelter is necessary to protect them during this state.

The pond used in these studies had turned over, mixing its water column by the time the second trial of Experiment III had been run (Paper Three of thesis). The water temperature had dropped to under 10 C and the crayfish we collected were very inactive. We believe that this experiment lends further evidence to the conclusion that crayfish seek shelter in colder weather.

Studies have shown structure to be important in warmer weather as well when crayfish are stocked at moderate to high densities in culture ponds or tanks. Karlsson (1977) believed that crayfish can be cultured in tanks up to a juvenile stage. To avoid cannibalism they must then be stocked out in ponds having a surplus of structure available. Momot (1967) and Momot and Gowing (1977) considered cannibalism along with other forms of non-predatory mortality to control crayfish populations to a larger degree than fish predation. In his studies with crayfish in small pools, Morrissy (1979) stocked juvenile crayfish just released from adult females at densities of $15/m^2$. He noted that when the amount of artificial structure present in these pools was reduced, survival of the crayfish dropped from 90% initially to 70%.

Structure was shown to significantly improve the survival of the caged crayfish in Experiment II. In this case, water temperatures were warmer,(up to 30 C), and we believed structure to be important for a refuge for molting crayfish. Survival of crayfish being fed in this experiment was greater when structure was present although the results were not statistically significant. Structure did significantly increase the survival of crayfish not being fed. If protection during molting was the only benefit supplied by structure in this experiment, it would seem that since the fed crayfish grew faster, (and molted more often), they would benefit more from the structure′s presence. Since this is not the case it is probable that the periphyton and other organisms growing on the tile structure provided a supplemental food source as well as a refuge.

Most of the crayfish feeding studies in the literature involve using vegetation or vegetation and animal wastes in pellet form as the food supplied to crayfish. Romaire, Forester, and Avault (1978) found that

feeding stunted crayfish smartweed (Polygonium sp.) and water primrose (Jussiaea sp.) lead to greater growth than when hay (Cyndon dactylon) was fed to the crayfish. Mills and McCloud (1983) noted that when crayfish were fed alfalfa pellets, growth was proportional to the amount of food added. Both Mills and McCloud (1983), and Morrissy (1979) report that excessive feeding may have led to low dissolved oxygen,(DO), levels causing crayfish mortality.

In our experiment food was shown to significantly increase both growth and survival. No trace of the food fed to the crayfish or remains of dead crayfish was ever found within the cages. The food conversion ratios calculated from this study are higher, implying less efficient conversion, than those reported by Morrissy (1979). It is important to realize that in his study the food was dry food pellets and in this work the food was wet fish chunks. In some quadrants being fed, mortality of the crayfish drastically increased the FCR we measured.

Much research has been done concerning stocking densities of crayfish and the growth that results at different densities. Studies with cultured crayfish indicated that crayfish stocked at higher densities grew more slower than those stocked at lower densities (Goyert and Avault, 1978; Huner and Romaire, 1978; Mills and McCloud, 1983). Flint and Goldman (1977) reported that in Lade Tahoe, crayfish were found in the highest densities in shallow water among the rocks and cobbles. The believed that these crayfish were smaller and matured at a shorter length compared to those found at sparser densities in deeper water. Romaire et al. (1978) found that when crayfish from a stunted crayfish population were placed in pools at reduced densities, they resumed growth.

In our study, over the range studied in Experiment I, stocking density had no significant effect on either the growth or survival of the caged crayfish. Morrissy (1979) and Romaire et al. (1978) also found no change in survival in their stocking experiments. If Experiment I had continued for a longer duration, or if a wider range of densities had been examined, differences in growth and survival may have become significant.

Morrissy (1979) concluded his work with an analysis suggesting that only 6% of the variation in growth rate was due to initial stocking density, and only 0.8% due to the feeding rate. His analysis calculated that 86% of the variation in growth was due to the initial size of the crayfish stocked and seasonal changes in water temperature. Jackson (1972) concluded that the small size of crayfish present in his ponds to be due to their being overcrowded. Without predators to control their numbers he thought crayfish growth in the ponds he studied to be limited by the amount of food available. In Paper 1 of this thesis we found slower growth in a higher density pond compared to one of lower density.

We believe that the different mortality present within the four cages is a consequence of low DO. The circulationpattern of water within the pond may have resulted in a microclimate of water low in DO surrounding the two western most crayfish cates. DO has been demonstrated to be important in determining crayfish distribution (Paper Three of this thesis). Ponds being considered for crayfish culture need to have their DO levels monitored frequently throughout their entire volume.

This study has shown that crayfish can be maintained in farm ponds within cages over several weeks. These caged crayfish survive and grow especially if fed and if artificial structure is present. Structure appears to be especially important to this species which is not know to

burrow extensively. Artificial structure is also readily utilized by crayfish that are free to move within the pond.

By examining the results of this and other experiments, the optimal stocking densities, the necessary quality and quantity of food can begin to be determined for crayfish. Much more work has to be done yet to determine the potential of crayfish as a resource in Kansas.

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GROWTH AND DISTRIBUTION OF THE CRAYFISH

Orconectes nais IN KANSAS FARM PONDS

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ABSTRACT

Crayfish are considered a major resource in the southern United States, especially in Louisiana. Basic information concerning the habitat and growth rates of crayfish common in Kansas farm ponds is needed to assess the potential of this resource in Kansas. The objectives of this study were to determine the growth and distribution of crayfish in ponds and to examinethe parameters that effect them. This study was conducted in two Riley County farm ponds. The species investigated was Orconectes nais, a species commonly found in ponds throughout the central United States. Qualitative sampling was done with a small-meshed bag seine and quantitative sampling was done with a dropped box-trap of $1m^2$ sampling area. This type of sampling also permitted correlation of crayfish distribution with environmental parameters and seasonal behavior. Nearly all young- of-the-year crayfish collected in mid-June were no deeper than 0.25m; by November most were at least 0.75m deep. No crayfish were trapped where bottom water dissolved oxygen level was less than 1.8 ppm. The average density at the depth of greatest crayfish concentration was $89/m^2$ in Pond 1 and $19/m^2$ in Pond 2. Total numbers of crayfish per hectare reached 476,124 in Pond 1 and 62,638 in Pond 2. Maximum biomass measured in this study was 1,188 kg/ha for Pond 1 in September, and 220 kg/ha for Pond 2 in August. The average weights of young-of-the-year crayfish sampled in June were 0.13g in Pond 1 and 0.28g in Pond 2. By November they had grown to 4.5g and 7.4g respectively. Pond 1 had a more dense population and its crayfish grew more slowly. The growth of caged crayfish was also observed and the effects of stocking density, supplemental feeding and artificial structure examined. Supplemental feeding significantly increased the growth rate of these crayfish. Both feeding and additional structure increased the survival of caged crayfish.